

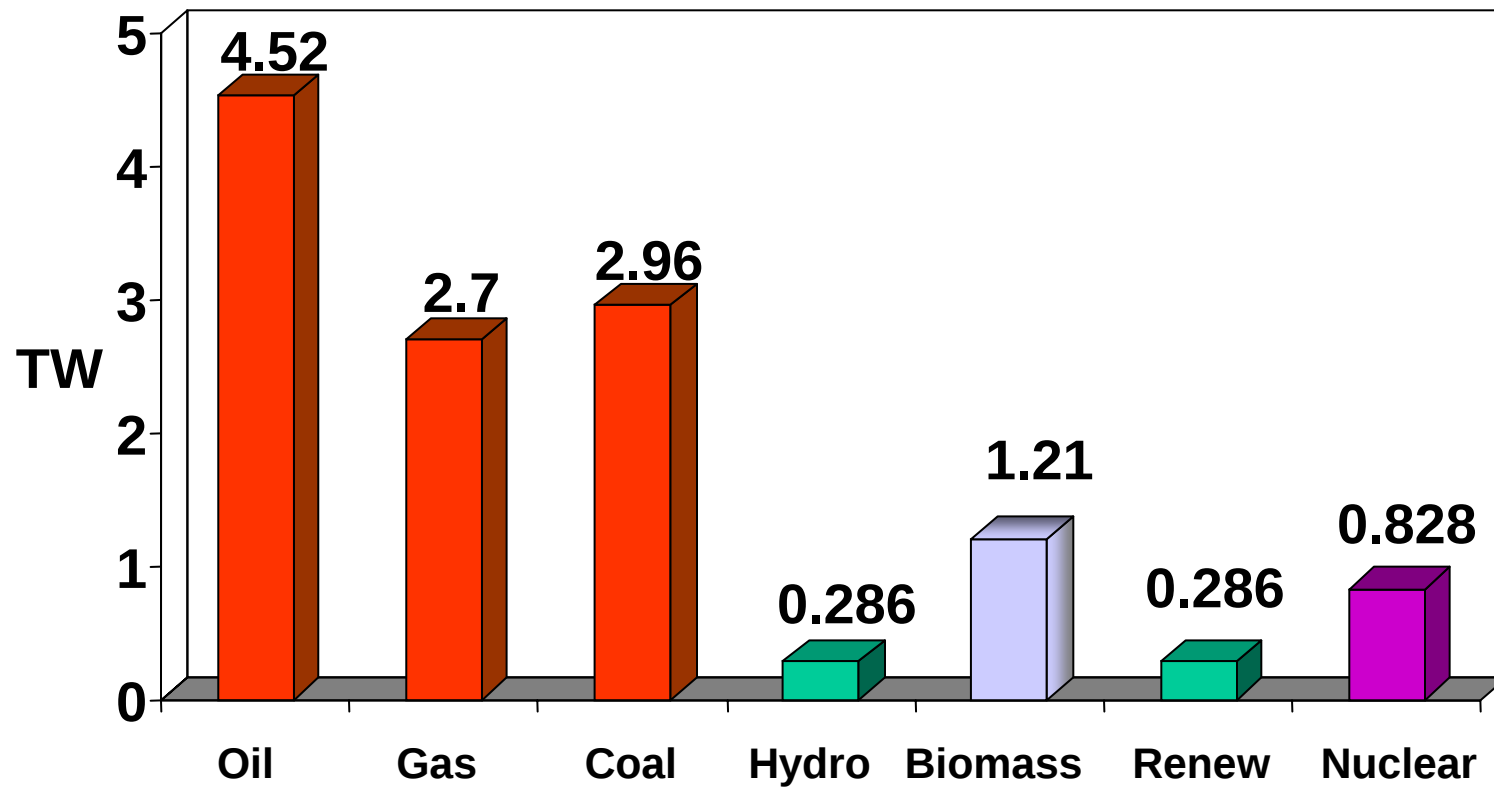
Development of Biofuels



Chris Somerville
Carnegie Institution, Stanford University, LBNL

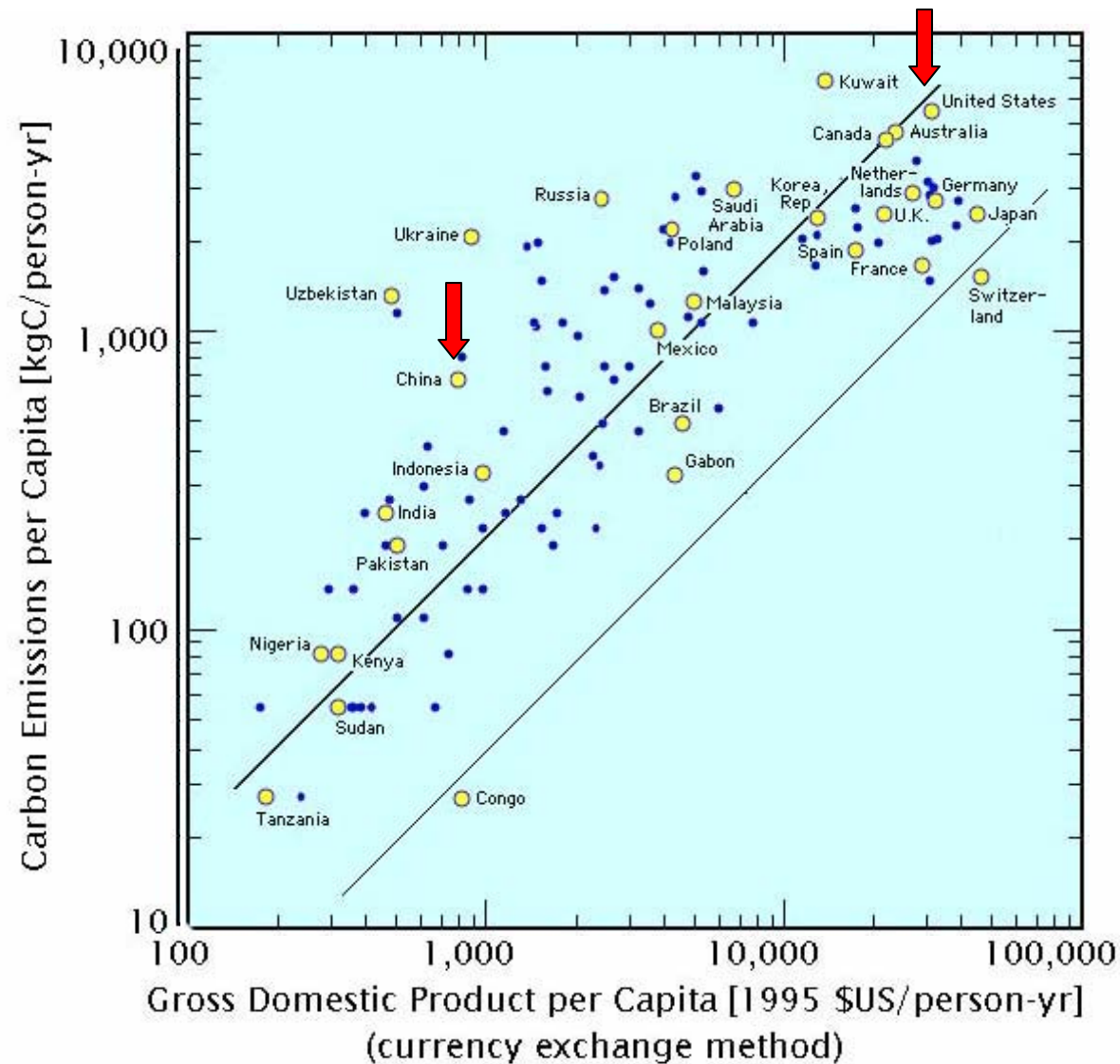
Mean Global Energy Consumption, 1998

(Total 12.8 TW)



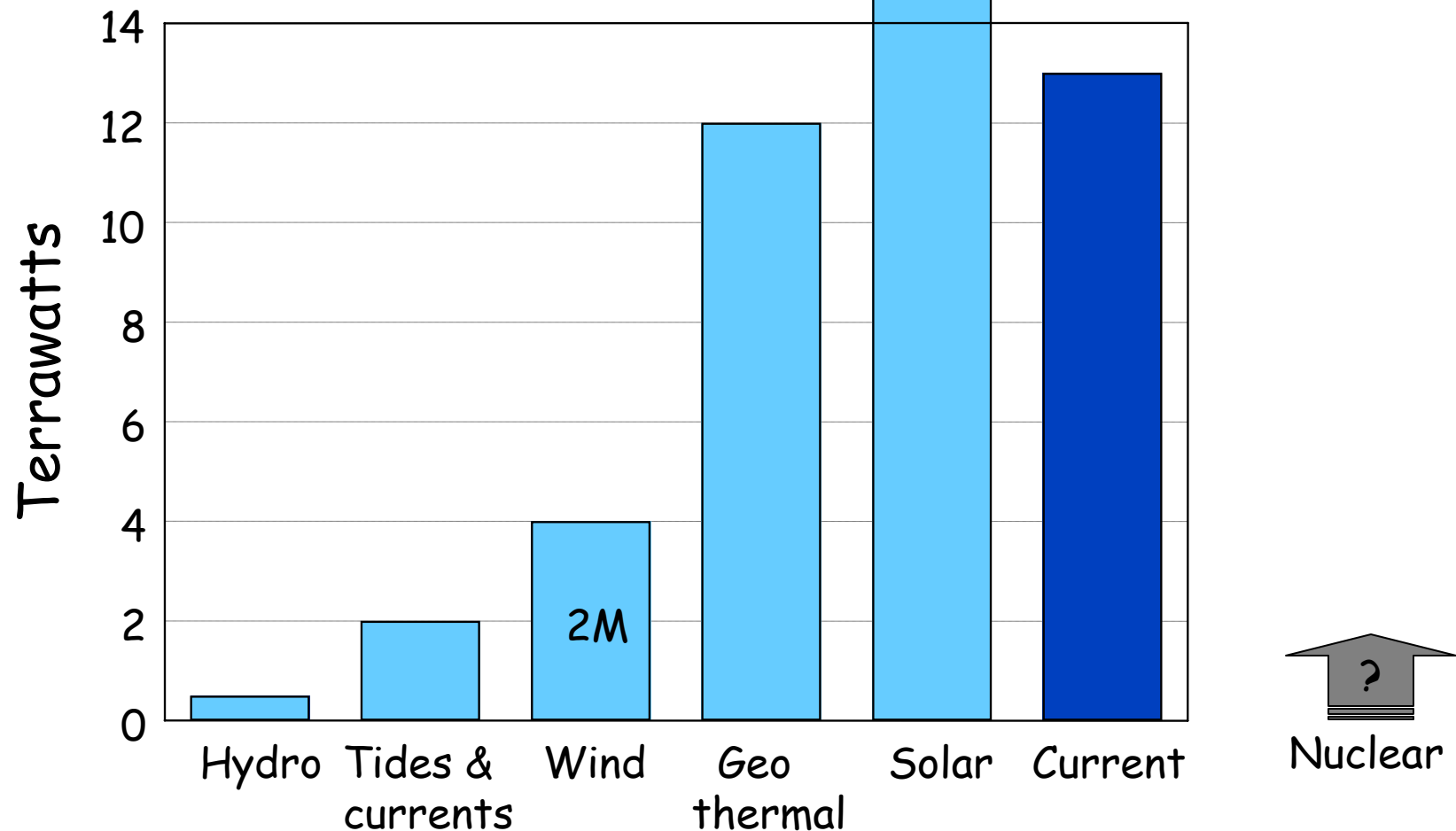
Nate Lewis, Caltech

CO₂ release rises with per capita GDP



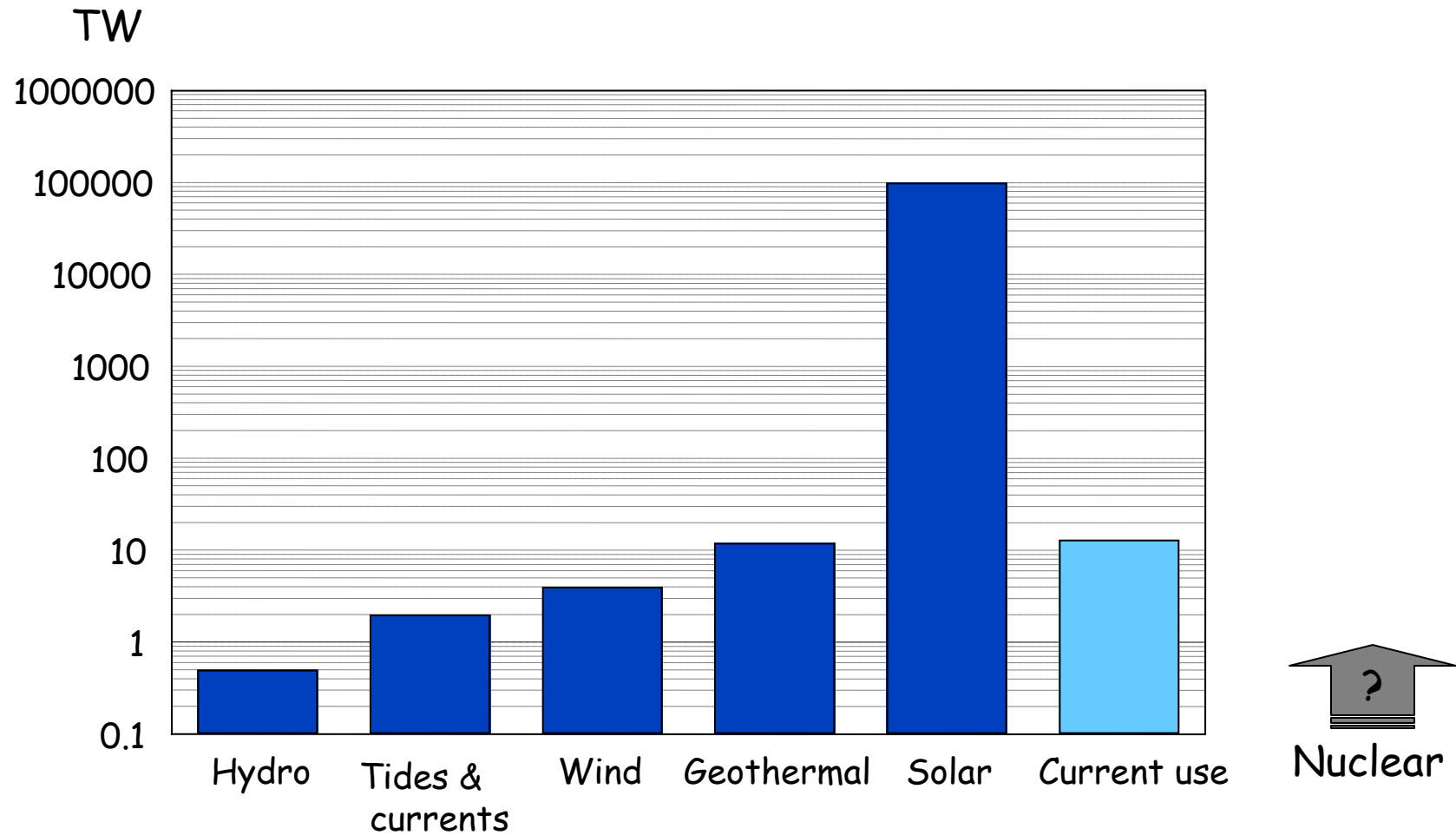
M Hoeffert

Potential of carbon neutral energy sources



From: Basic Research Needs for Solar Energy Utilization, DOE 2005

Potential of underused renewable energy sources



From: Basic Research Needs for Solar Energy Utilization, DOE 2005

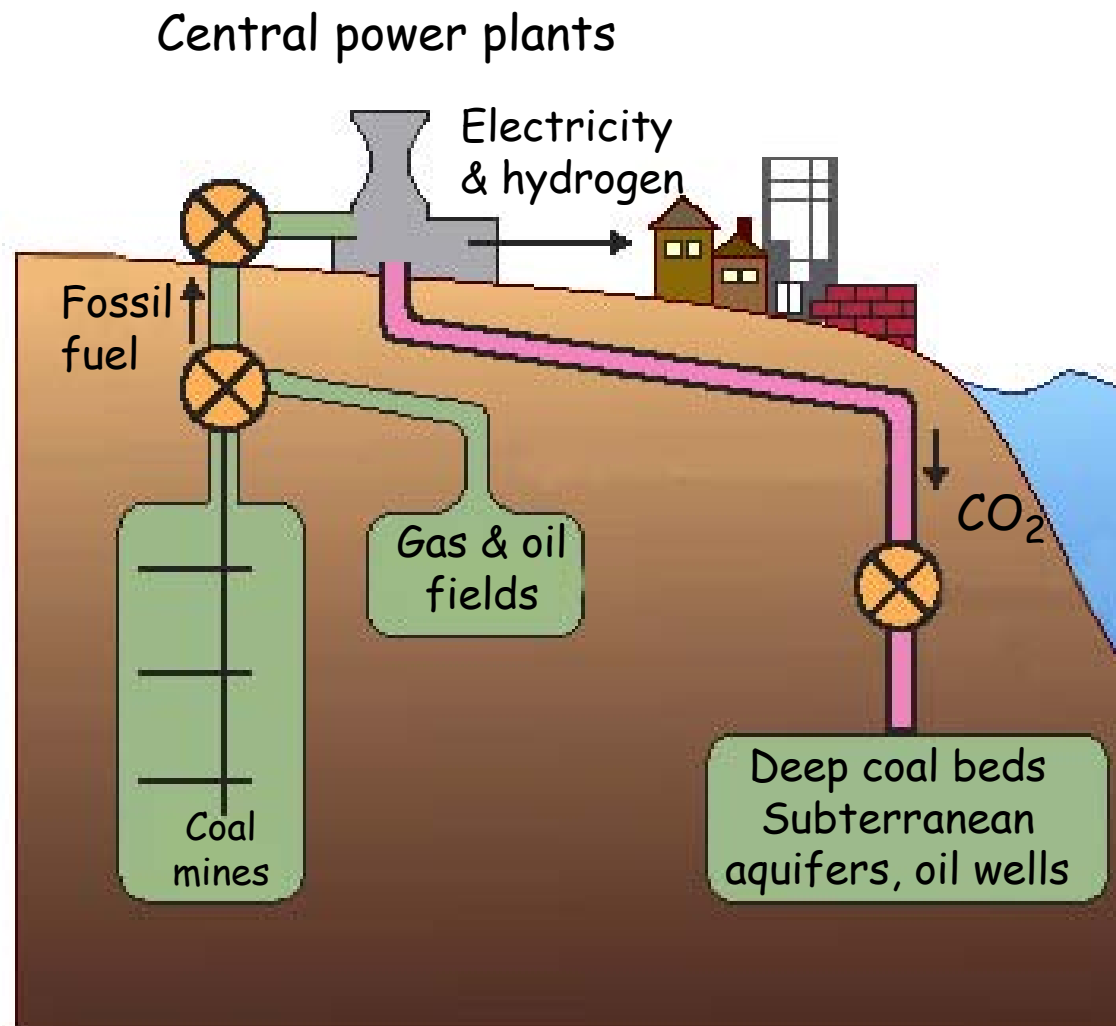
How much would every roof contribute if photovoltaic?

- 7×10^7 detached single family homes in U.S.
- ≈ 2000 sq ft/roof = 180 m^2 /home
- = $1.2 \times 10^{10} \text{ m}^2$ total roof area
- Hence can (only) supply 0.25 TW,
 $\approx 7.5\%$ U.S. Primary Energy Consumption

~160,000 km² of photovoltaic devices
would meet US energy needs



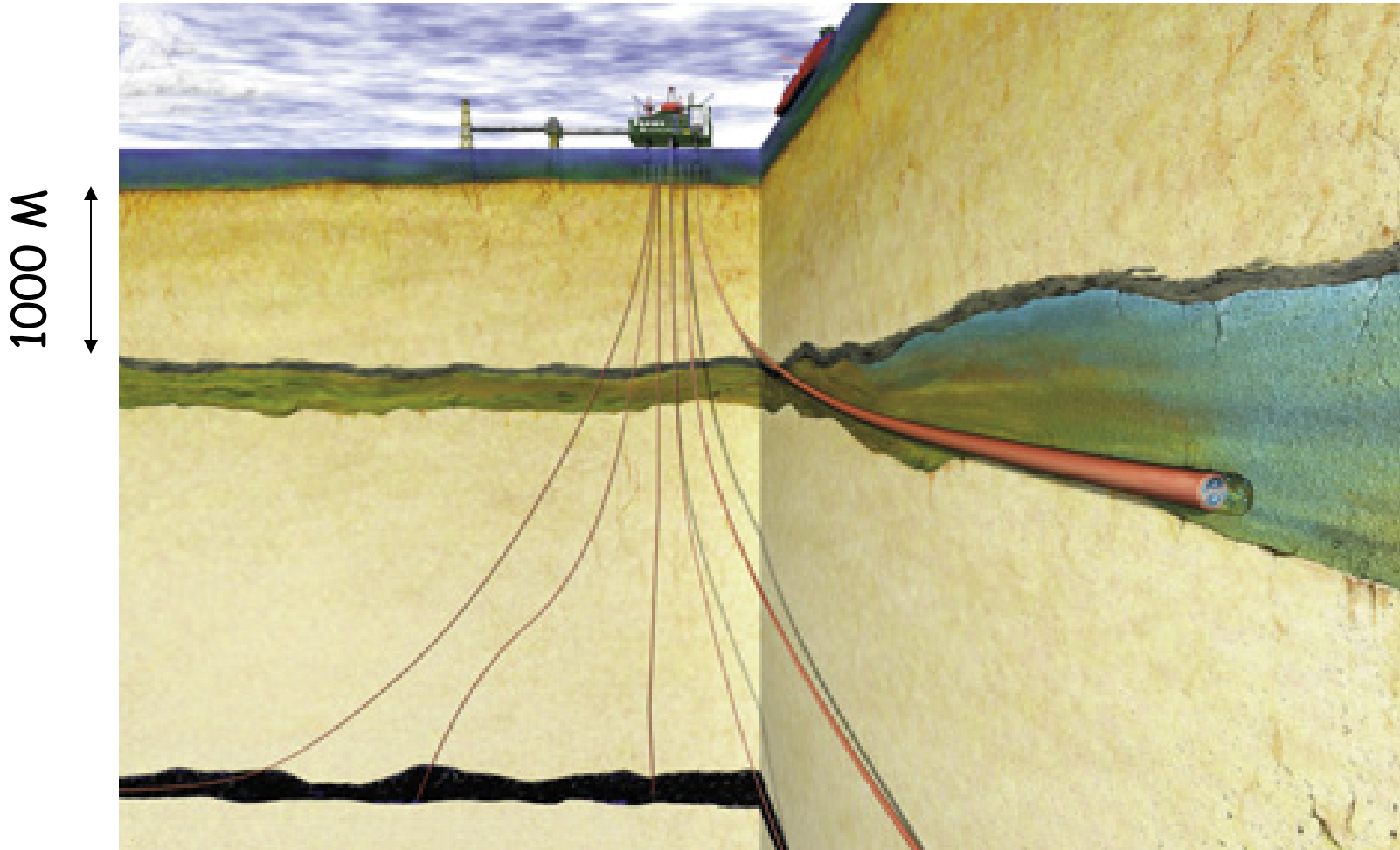
Sequestration vision



Modified from Hoffert et al. Science 298,981

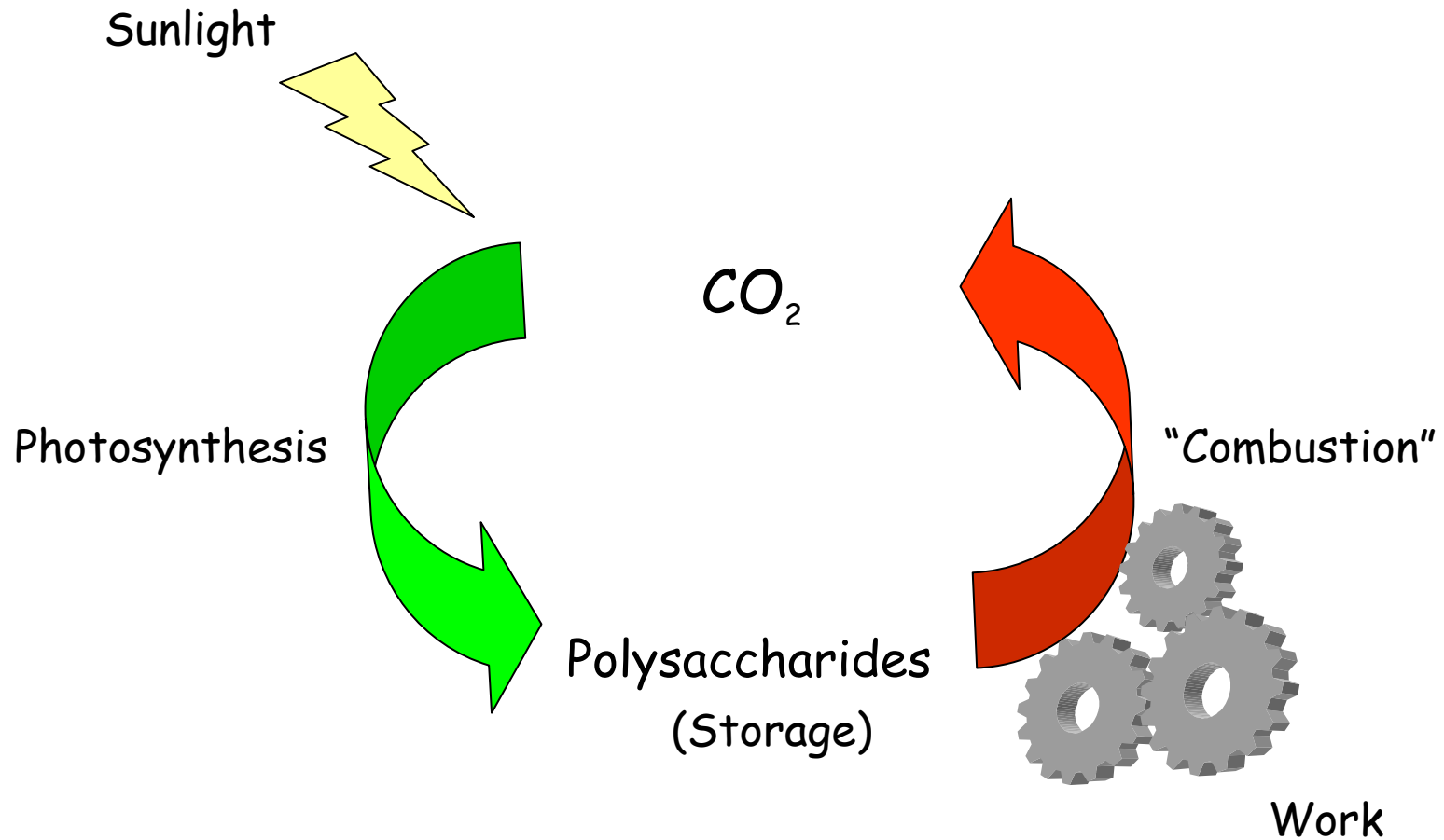
The Sleipner Experiment

1 million tons/y; capacity 600 B tons
7000 such sites needed

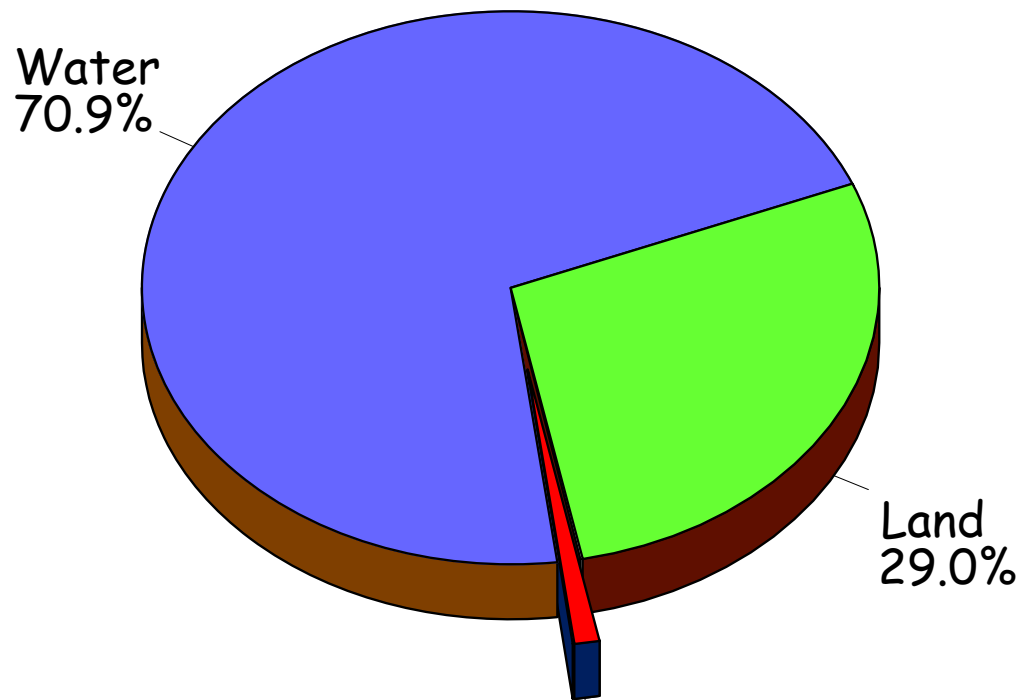


www.agiweb.org/geotimes

Combustion of biomass provides carbon neutral energy



90,000 TW of energy arrives on the earth's surface from the sun



Amount of land needed for 13 TW at 1% efficiency
5% of land
650 MHa

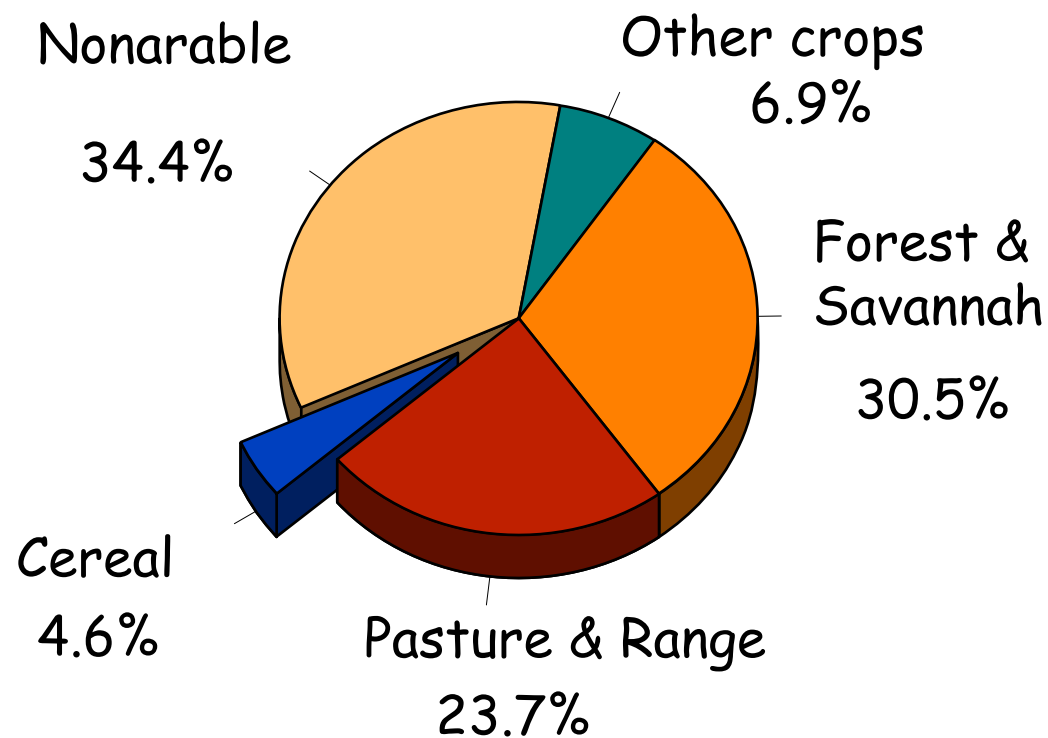
>2% yield is feasible

Yield of 26.5 tons/acre observed by Young & colleagues
in Illinois, without irrigation

Courtesy of Steve Long et al

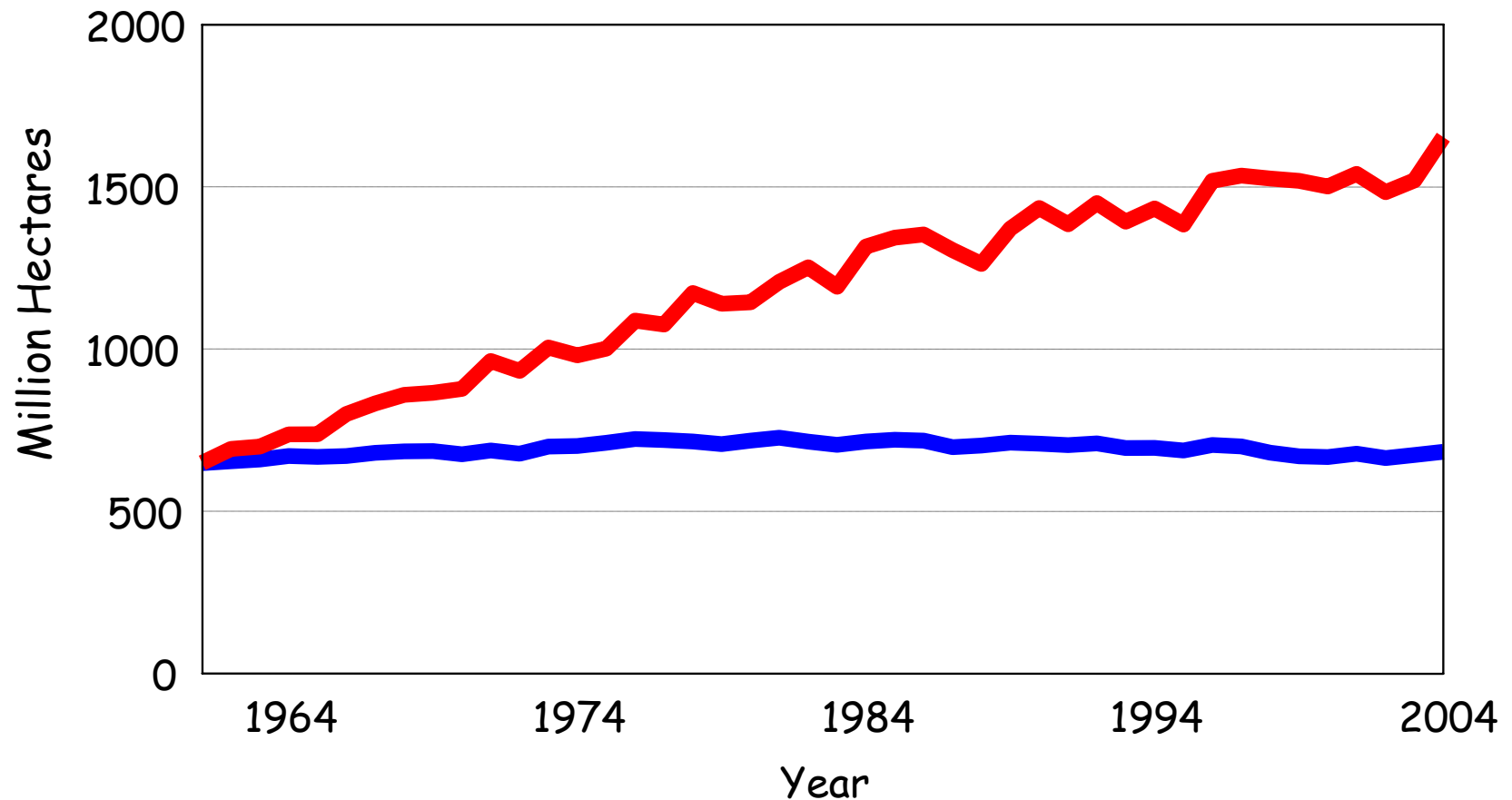


Land Usage



AMBIO 23,198 (Total Land surface 13,000 M Ha)

Global grain production with and without yield enhancements

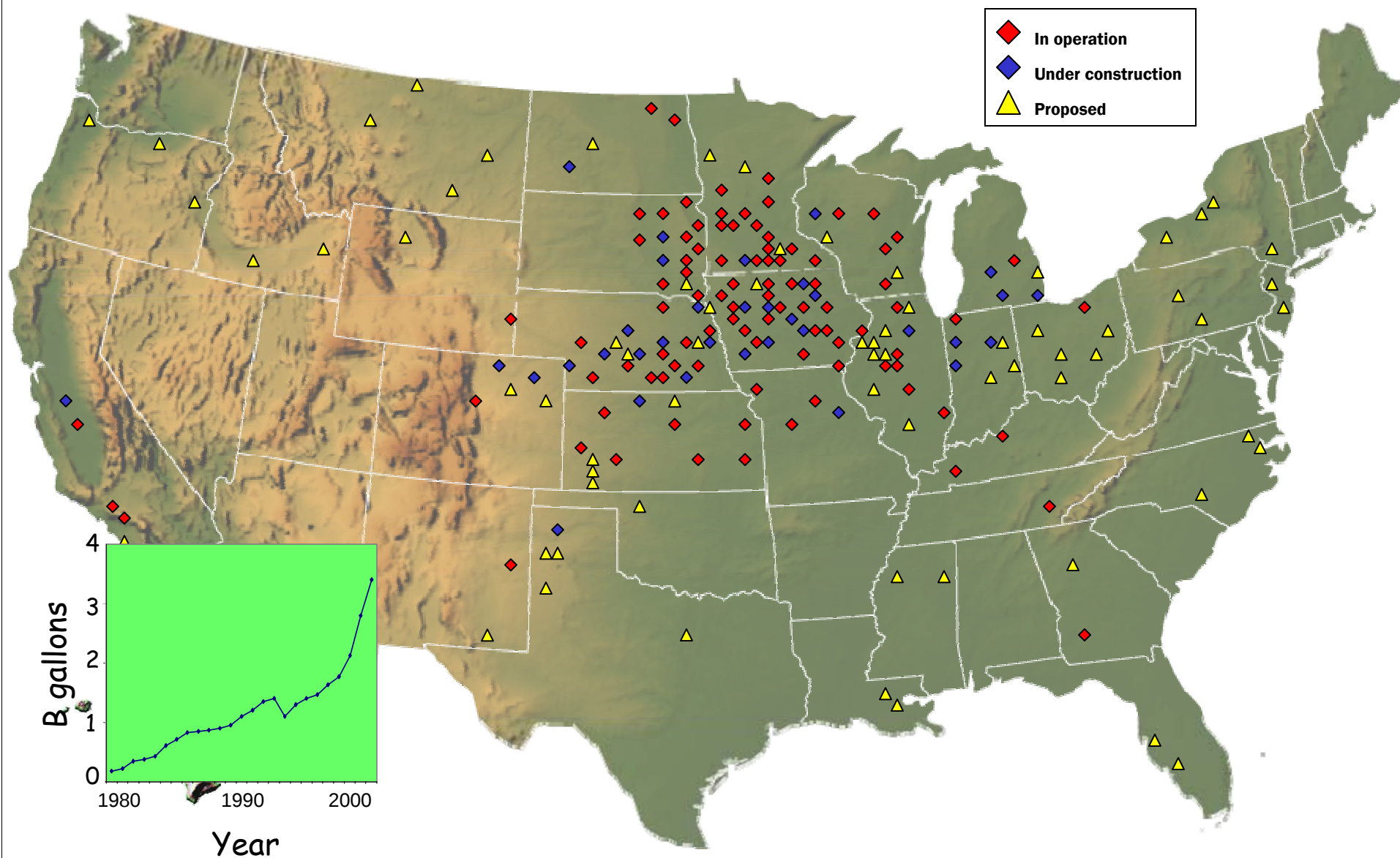


Data from worldwatch

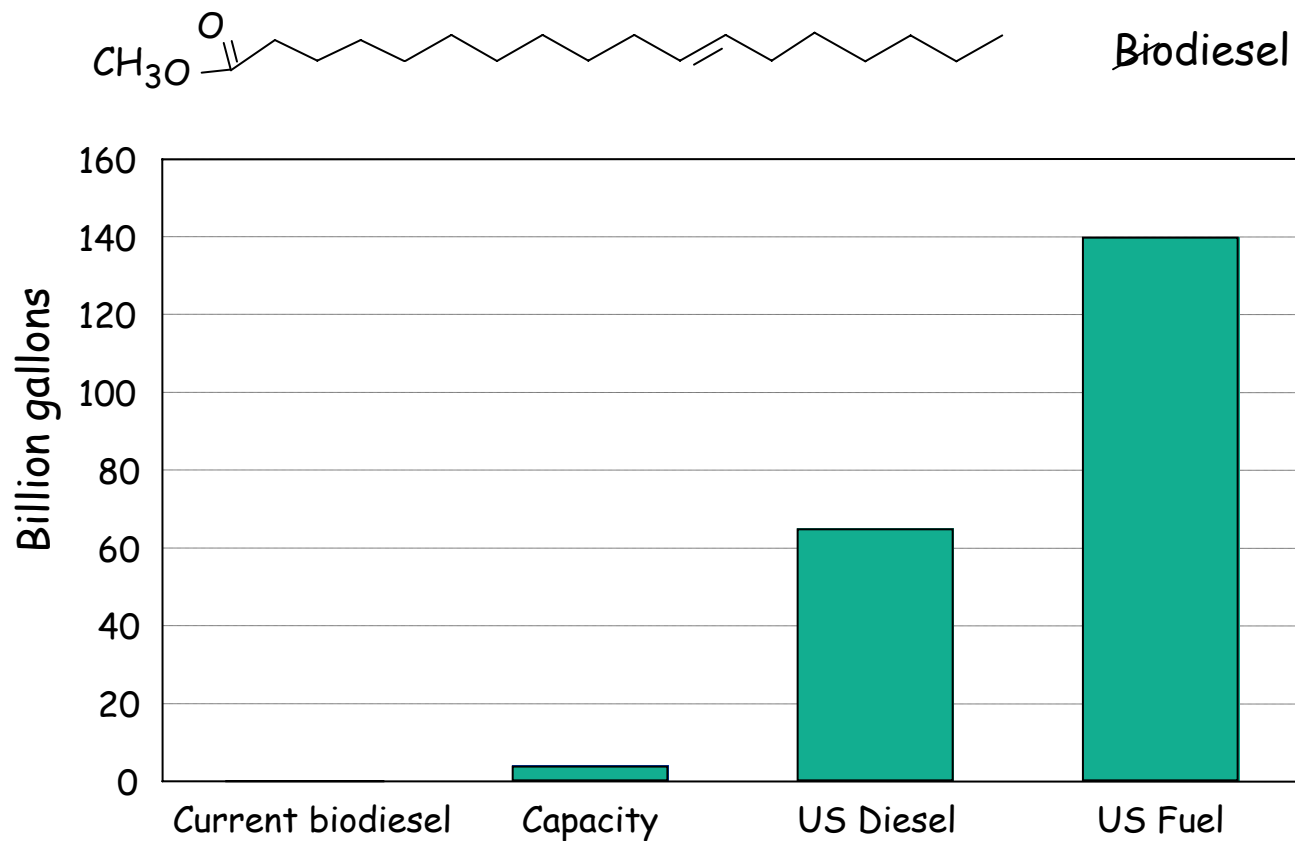


US Corn Grain Ethanol Plants

AS OF: March 2006

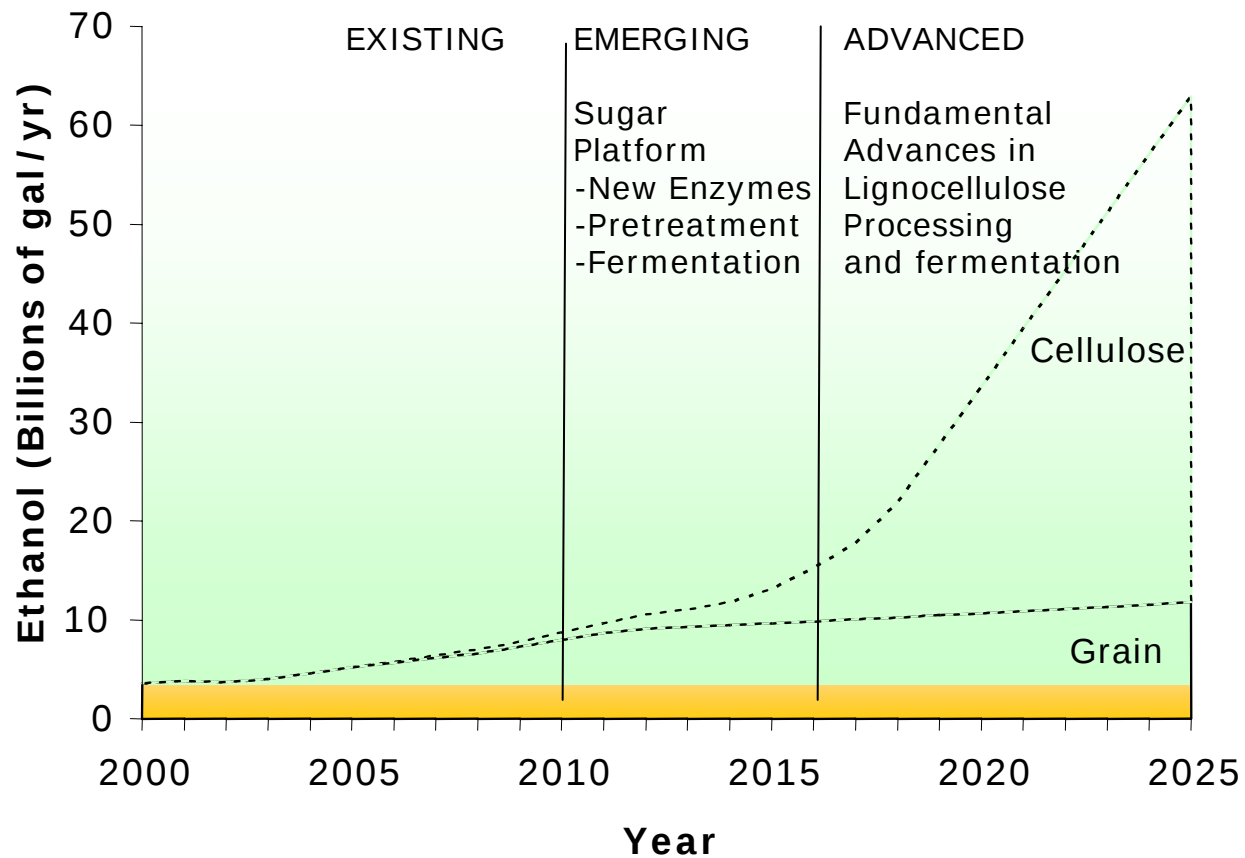


Limited potential of biodiesel



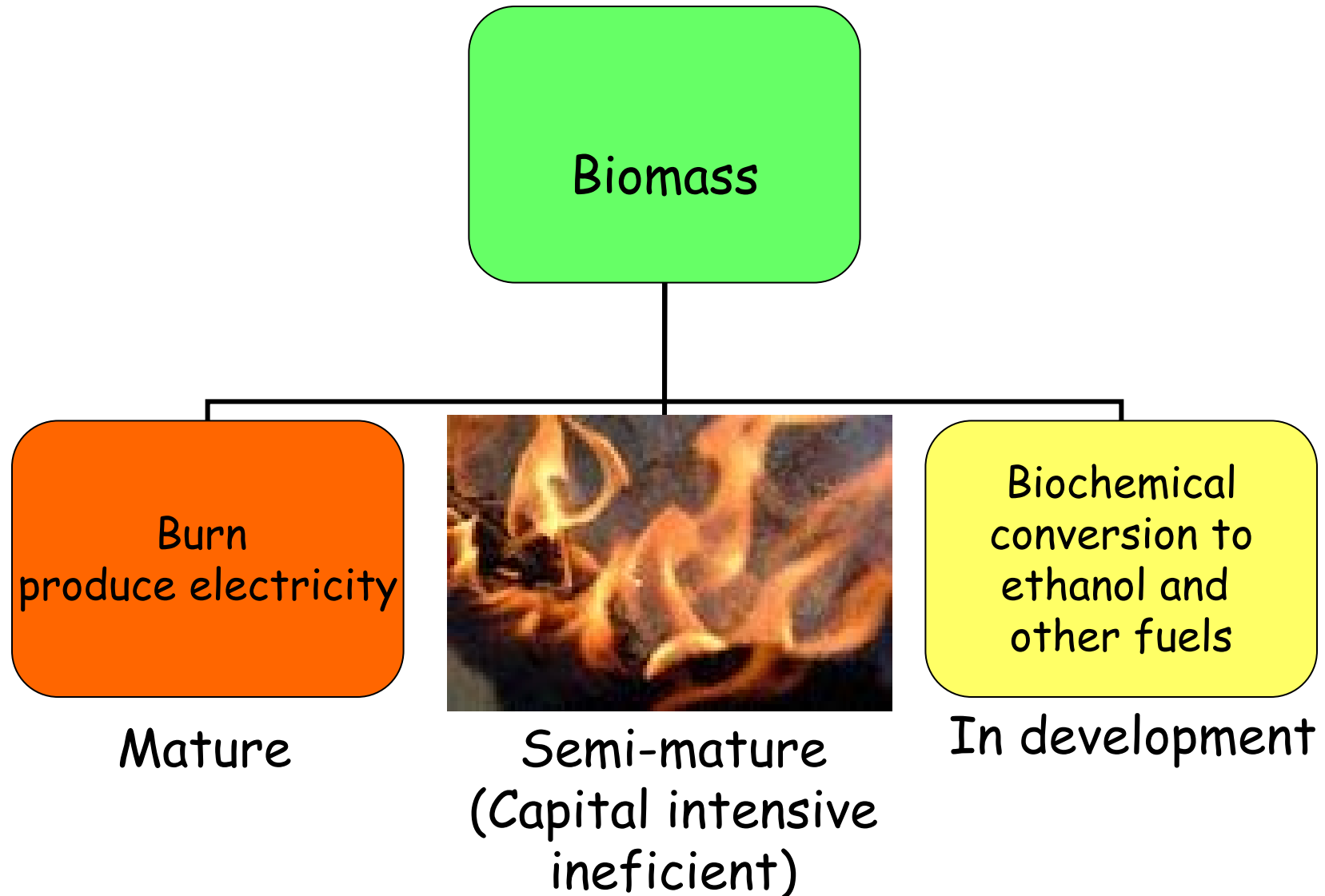
65 biodiesel companies in operation, 50 in construction 2006

A DOE Ethanol Vision

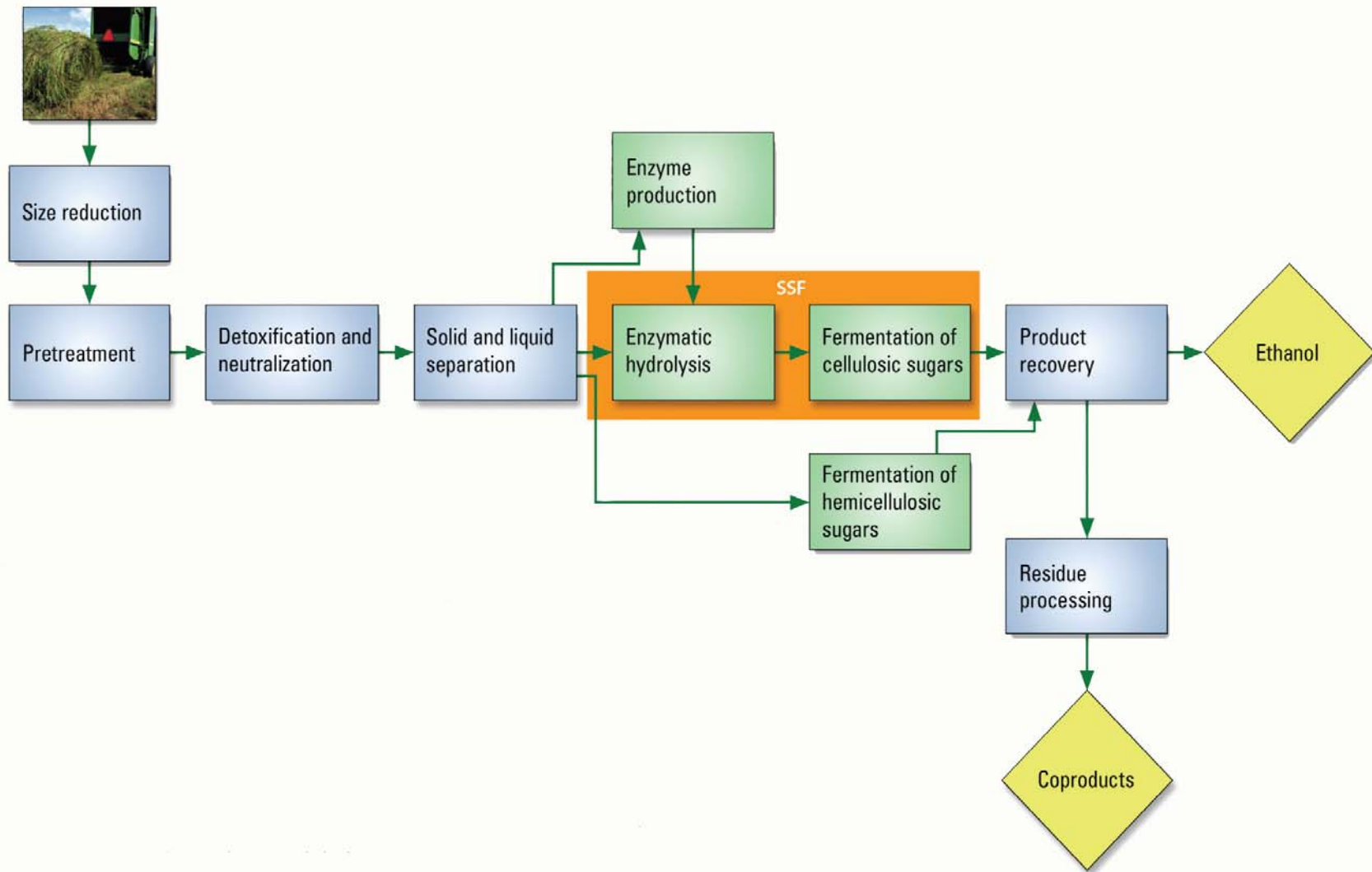


Modified from Richard Bain, NREL

How Biomass is Used for Energy



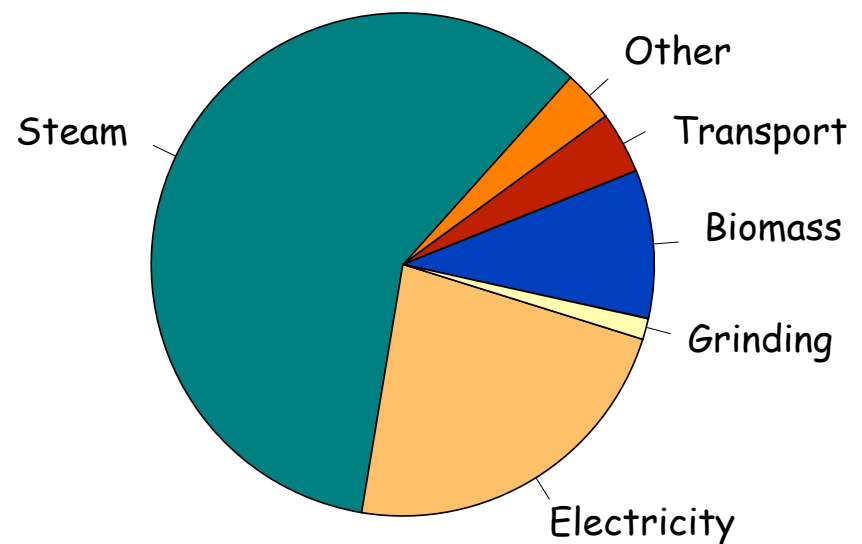
Steps in cellulosic ethanol production



From: Breaking the Biological Barriers to Cellulosic Ethanol

The challenge is efficient conversion

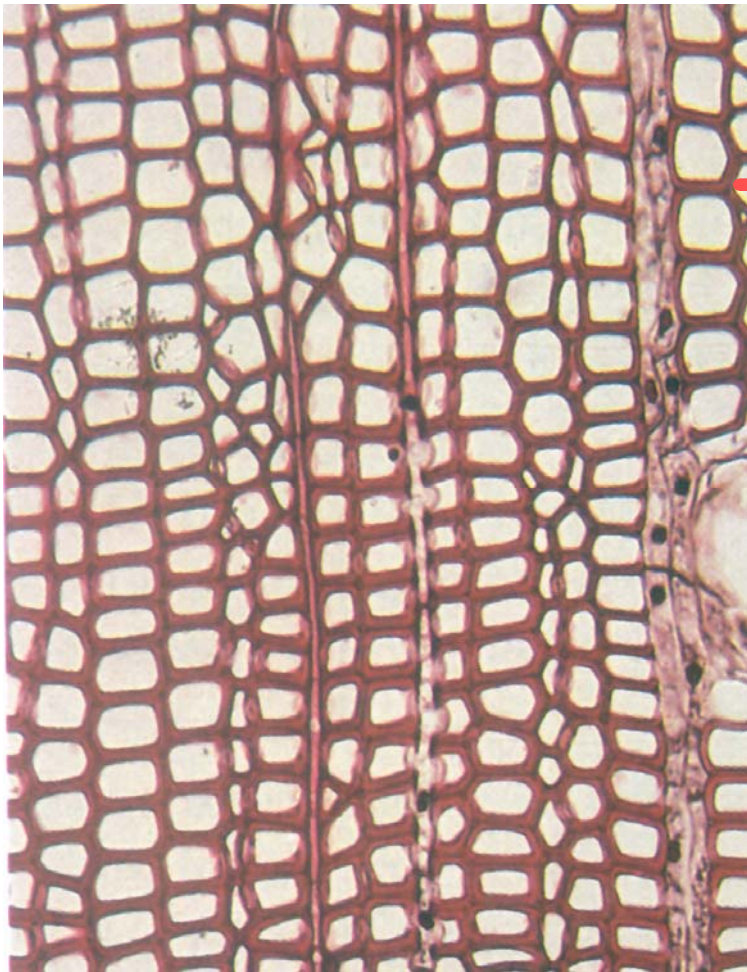
- Burning switchgrass (10 t/ha) yields 14.6-fold more energy than input to produce*
- But, converting switchgrass to ethanol calculated to consume 45% more energy than produced



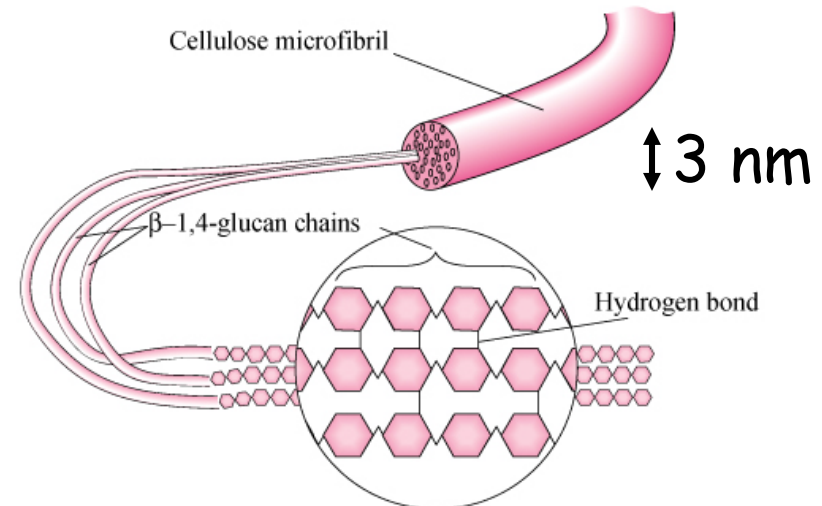
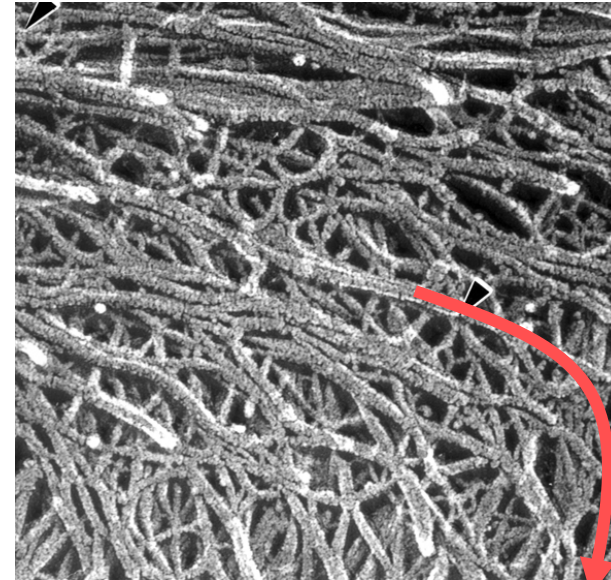
Energy consumption

*Pimentel & Patzek, Nat Res Res 14,65 (2005)

Plants are mostly composed of sugars

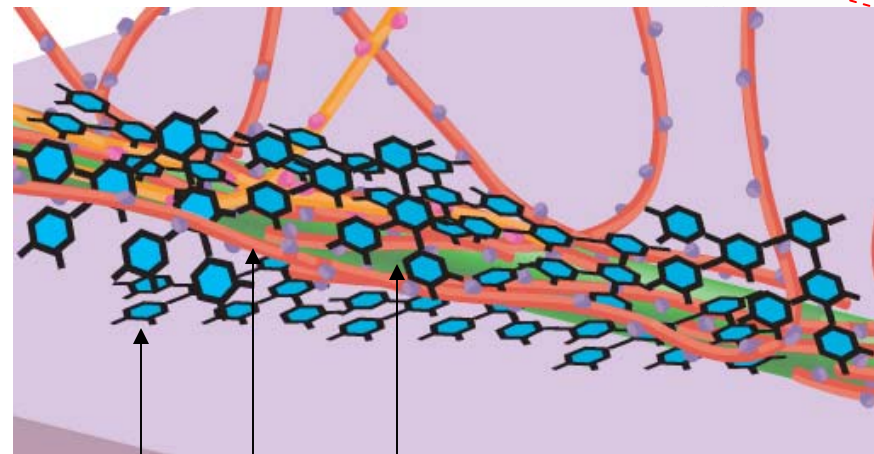
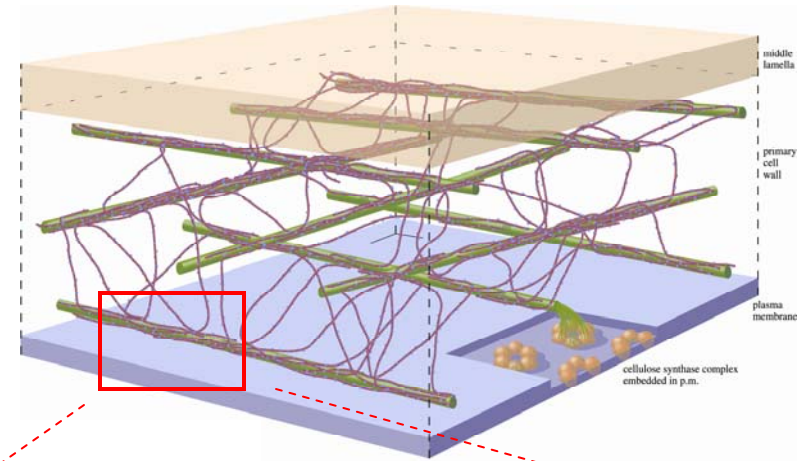
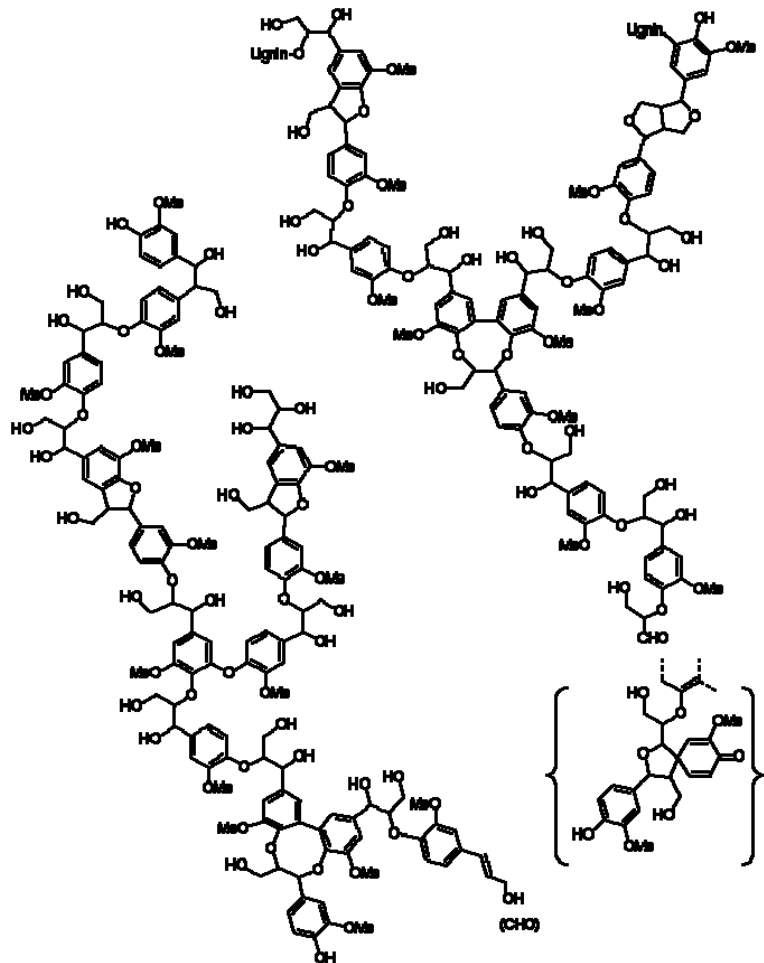


Section of a pine board



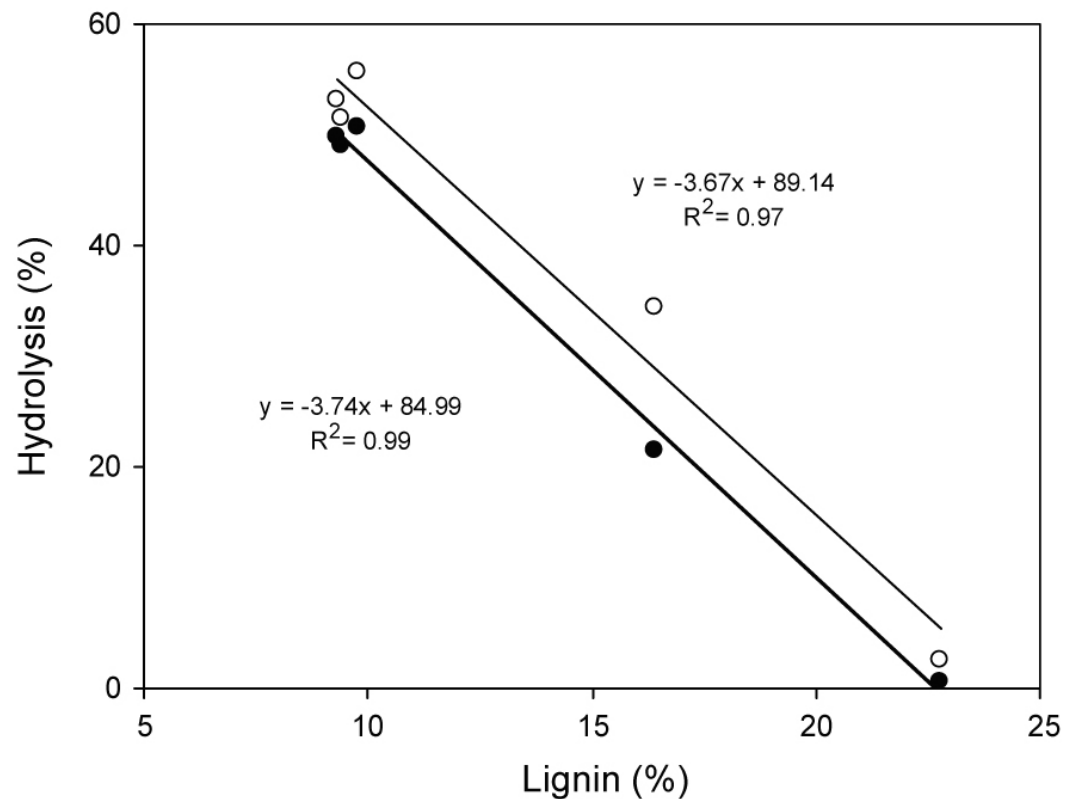
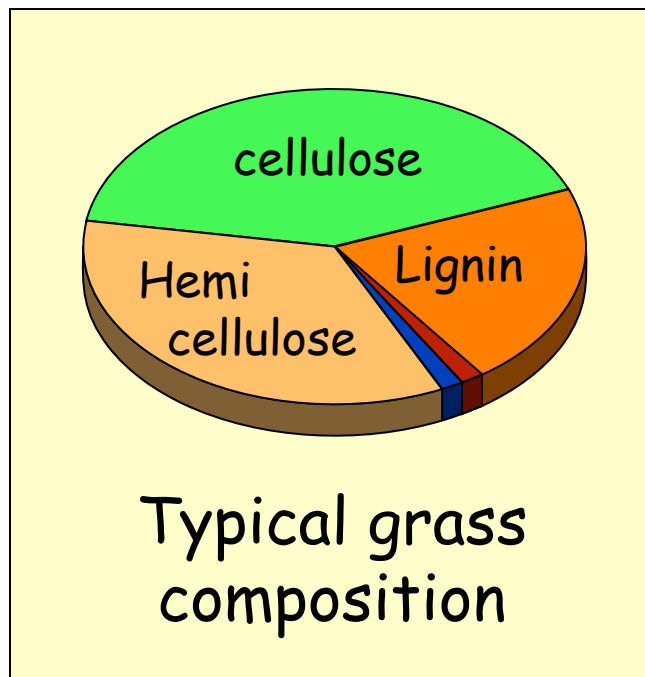
Polymerized glucose

Lignin occludes polysaccharides

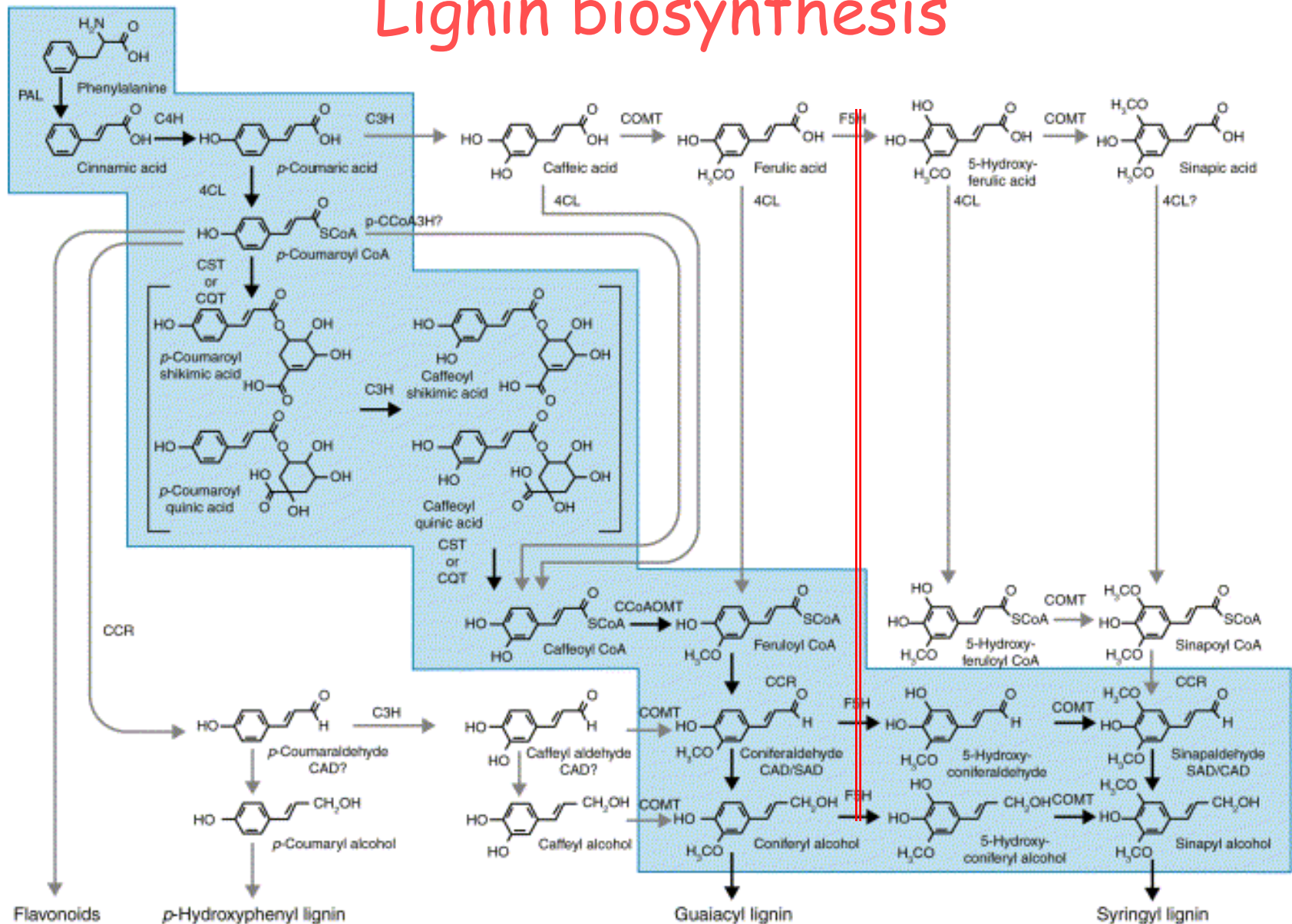


Lignin
Hemicellulose
Cellulose

Effect of lignin content on enzymatic recovery of sugars from Miscanthus



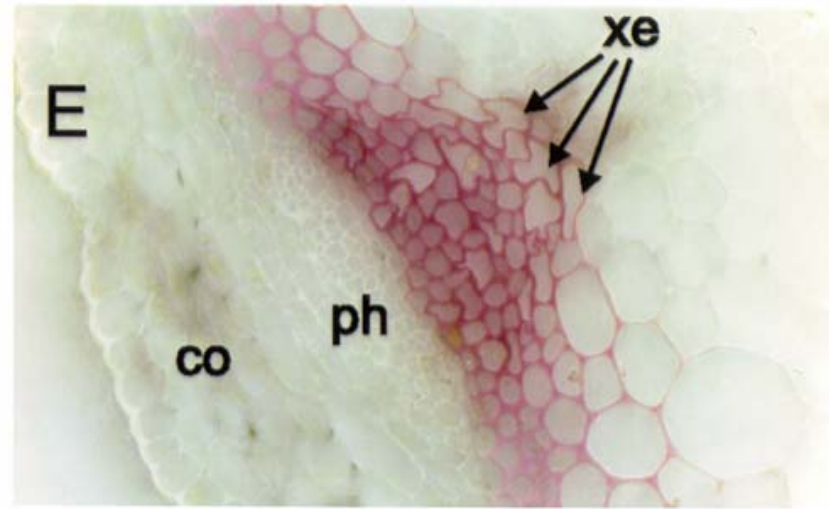
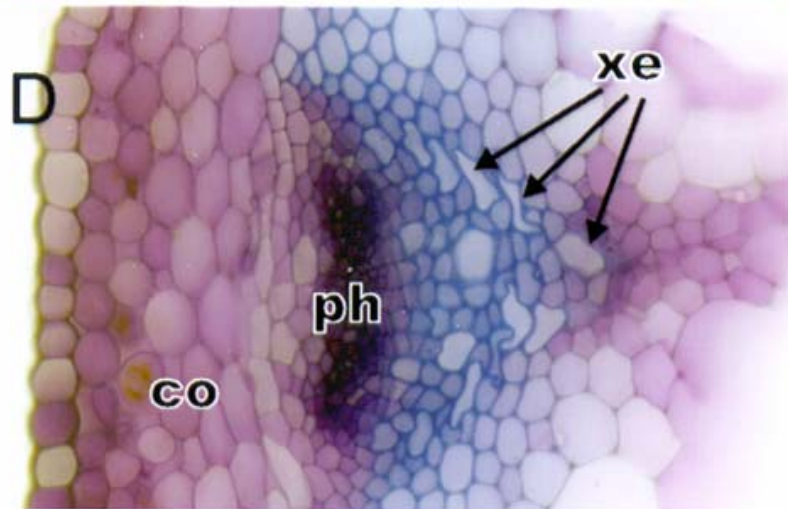
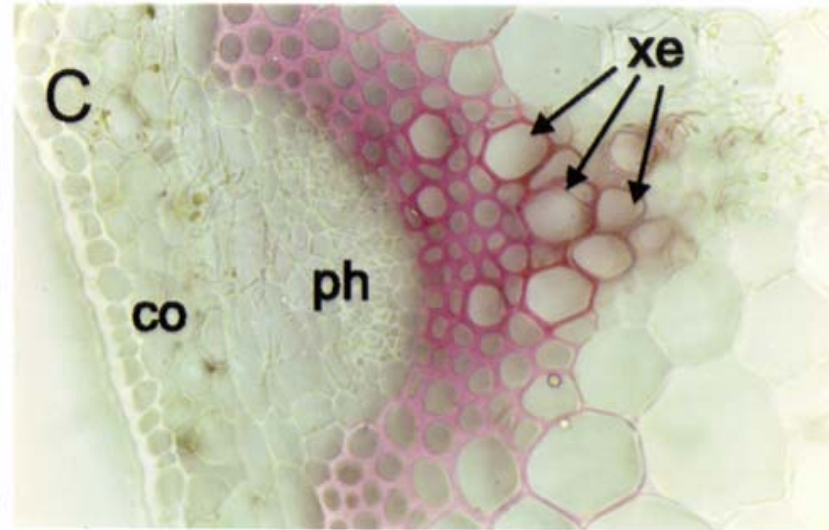
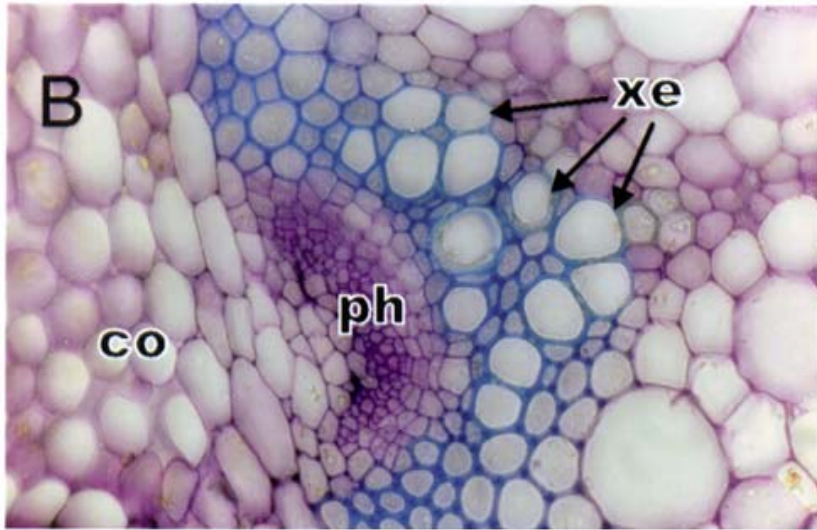
Lignin biosynthesis



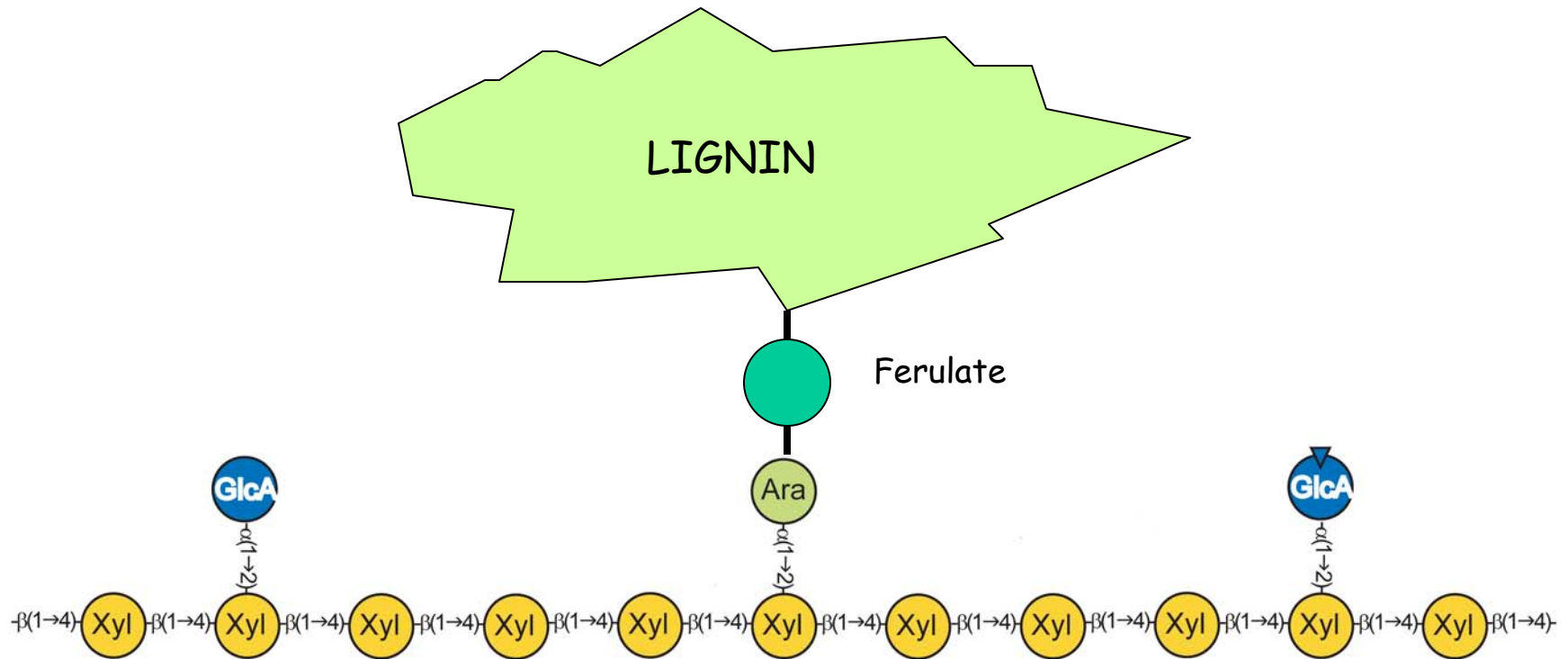
Current Opinion in Plant Biology

Humphreys and Chapple, Curr Opin Plant Biol 5,224

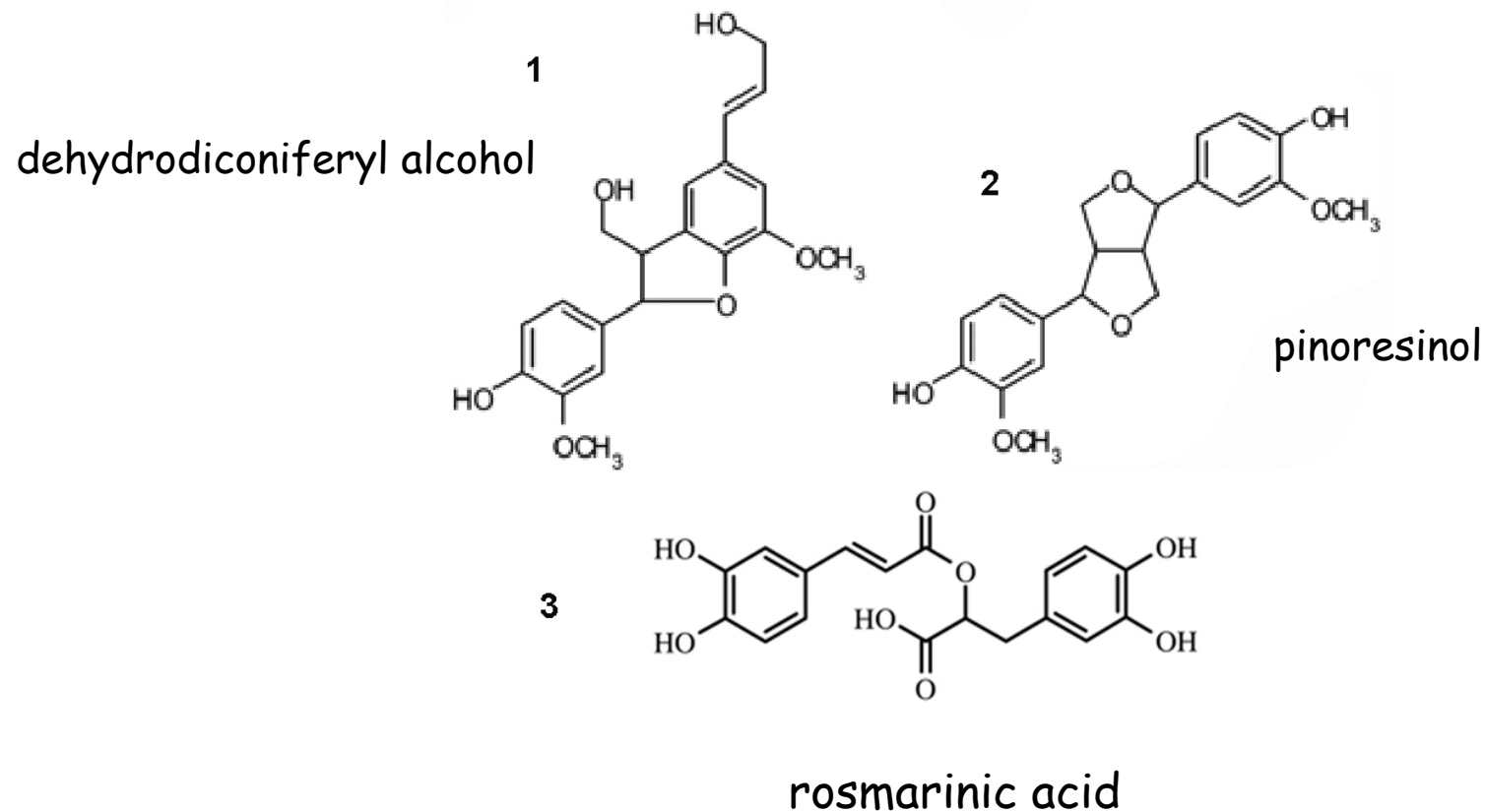
Irregular xylem (*irx*) mutants



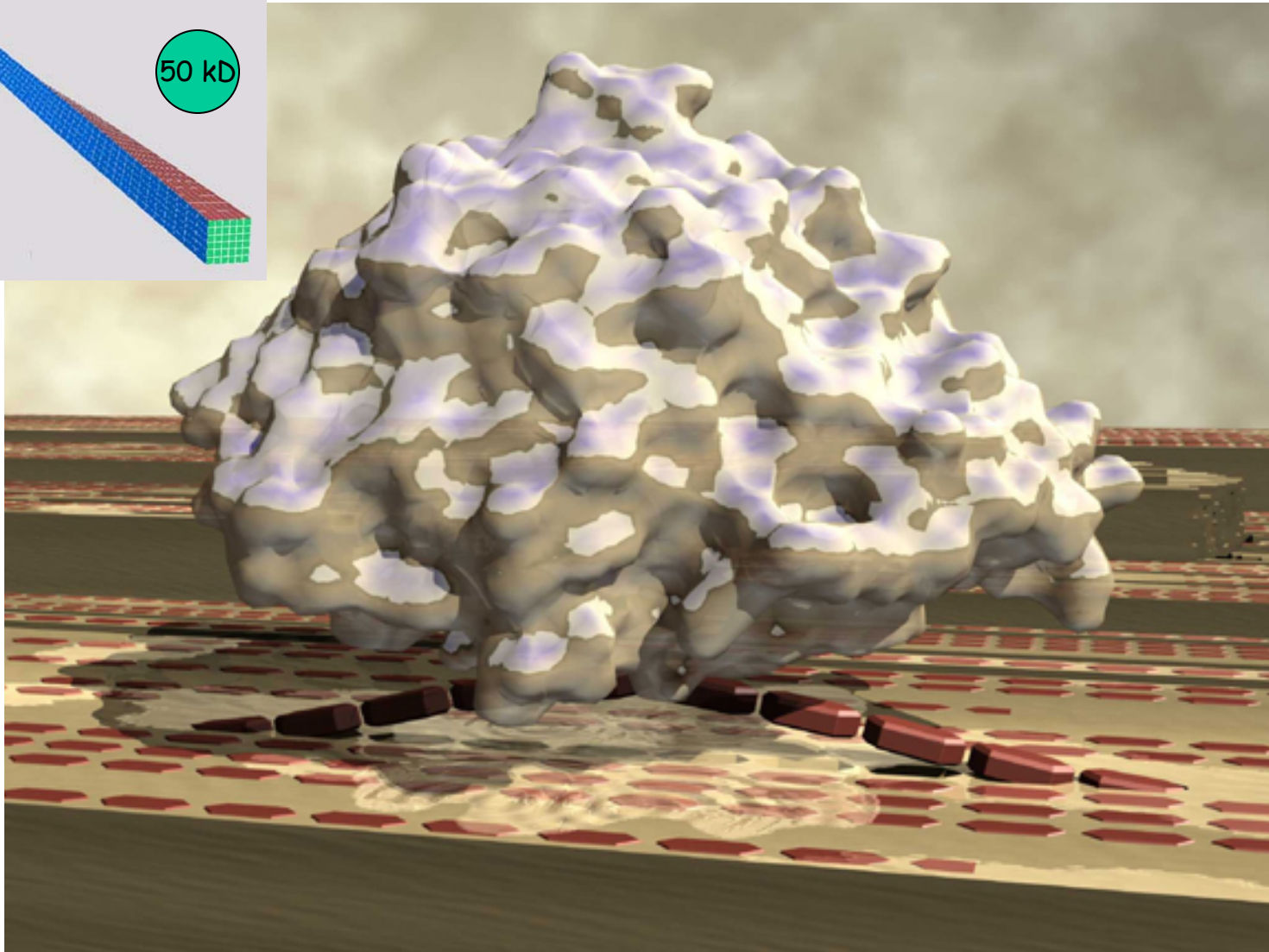
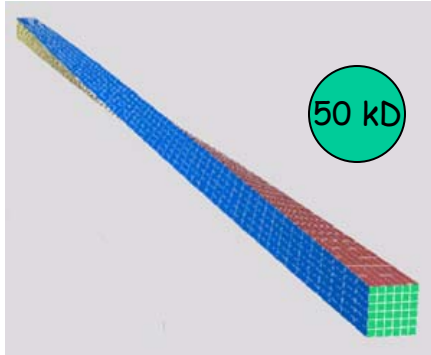
Lignin is covalently linked to hemicellulose (xylans)



A cleavable lignin precursor would fundamentally alter preprocessing

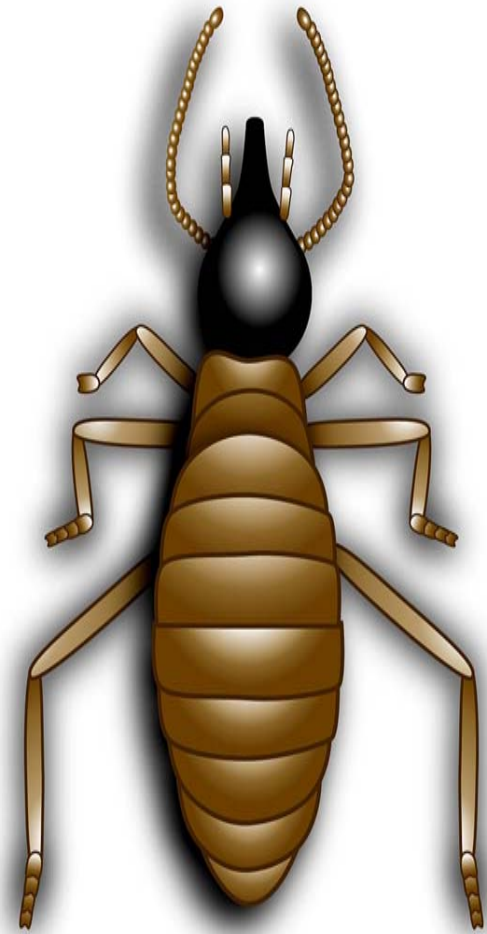


Cellulose is recalcitrant to hydrolysis

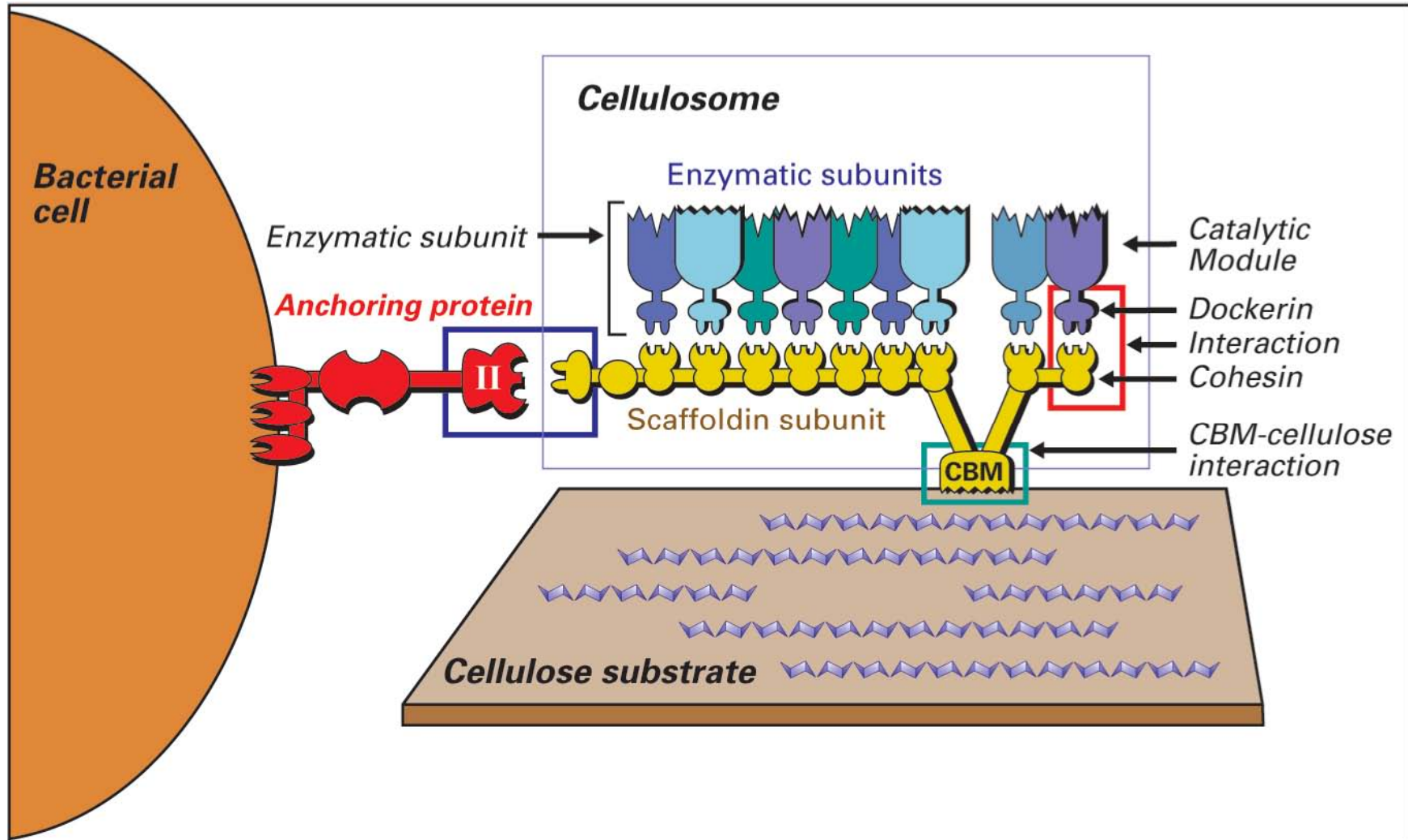


Possible routes to improved catalysts

- Explore the enzyme systems used by termites (and ruminants) for digesting lignocellulosic material
- Compost heaps and forest floors are poorly explored
- In vitro protein engineering of promising enzymes
- Develop synthetic organic catalysts (for polysaccharides and lignin)

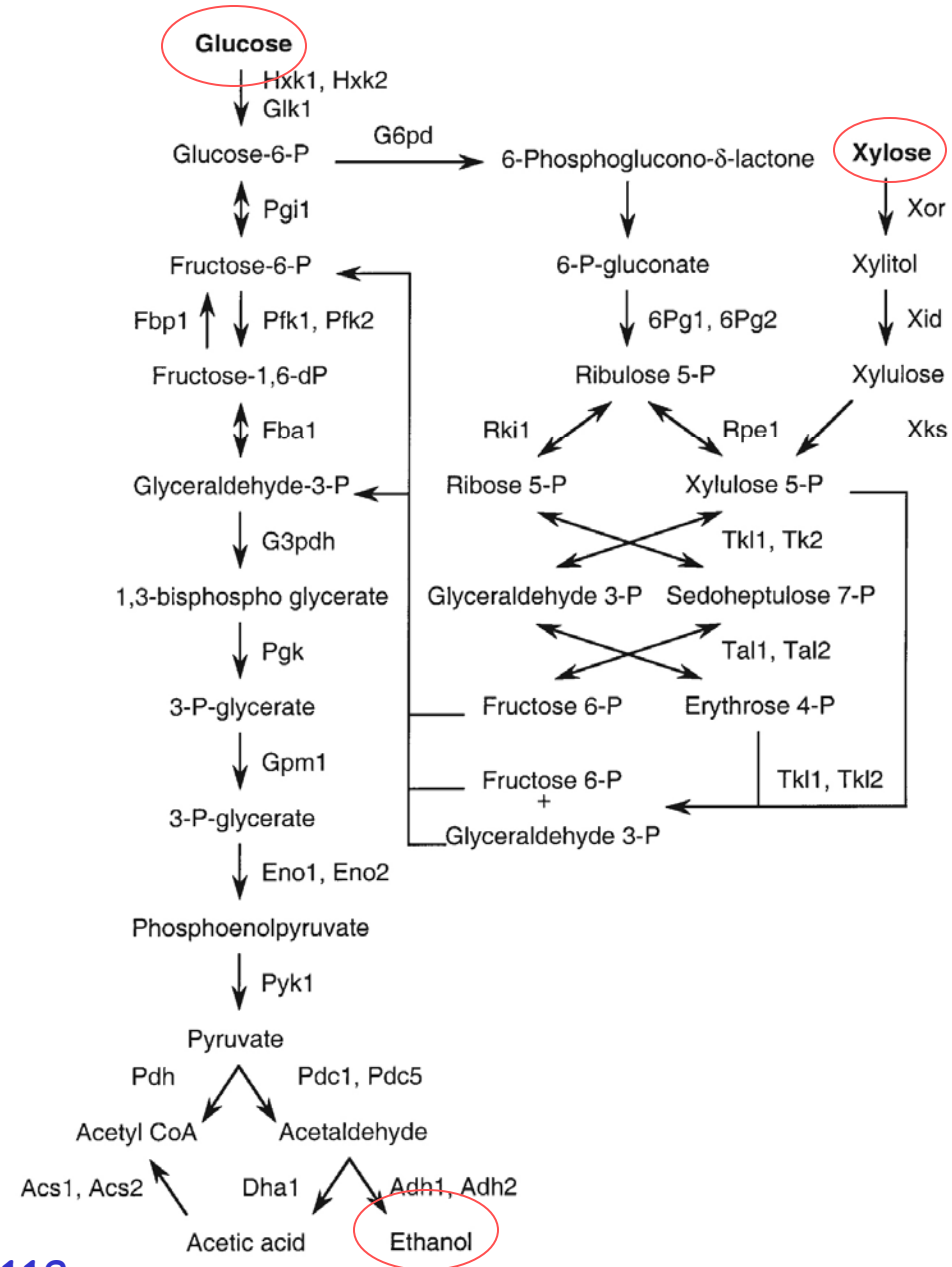
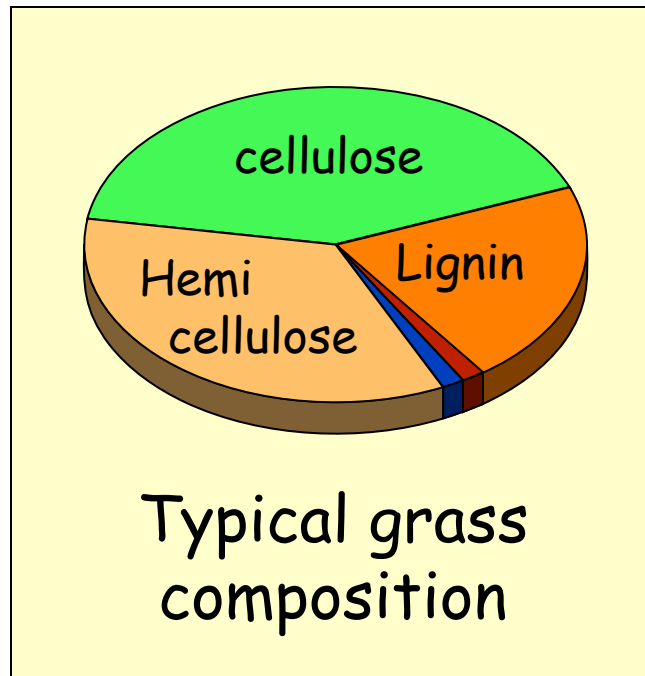


Some cellulytic enzymes are components of a "molecular machine"

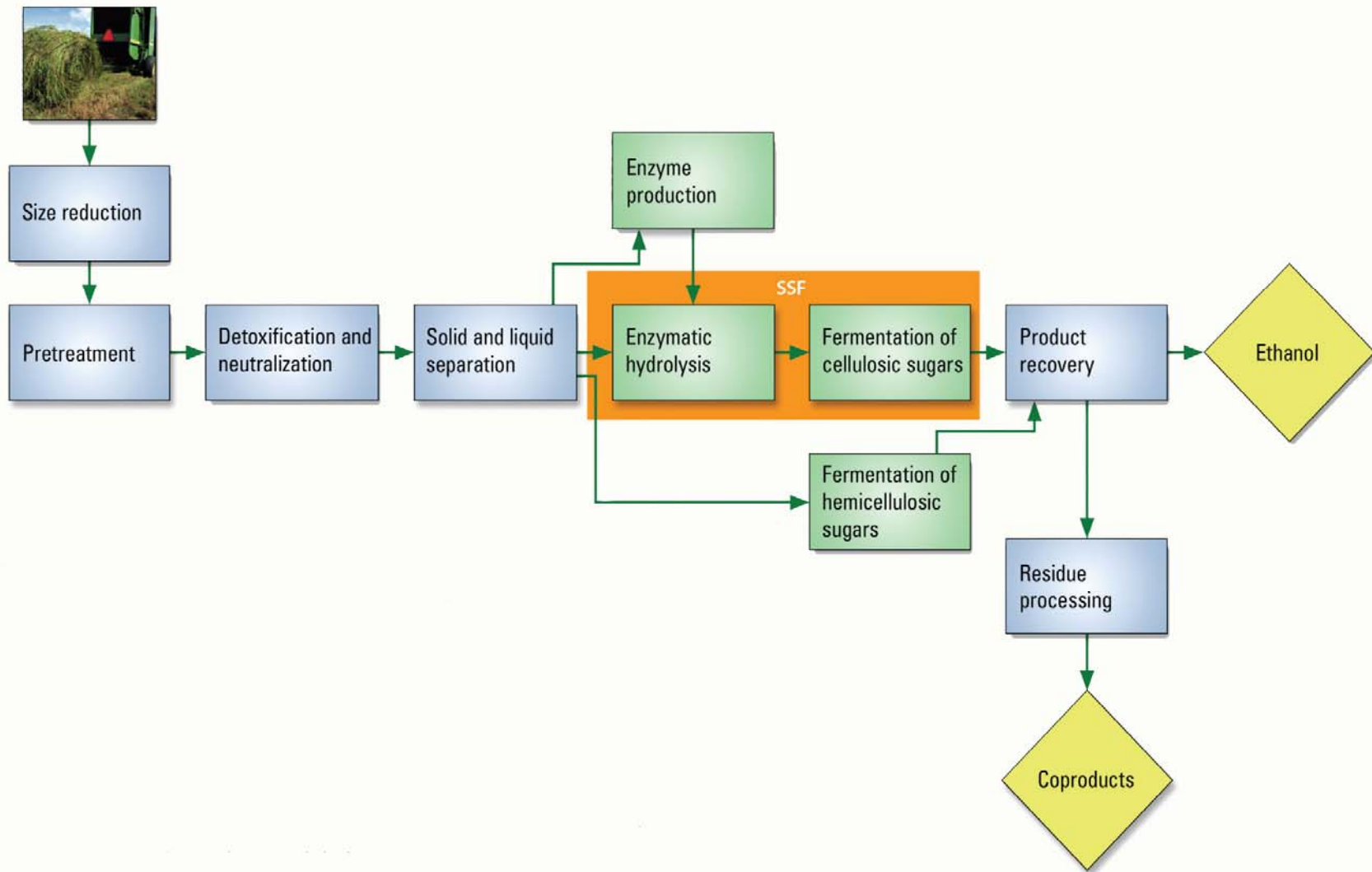


From: Breaking the Biological Barriers to Cellulosic Ethanol

Fermentation of all sugars is essential



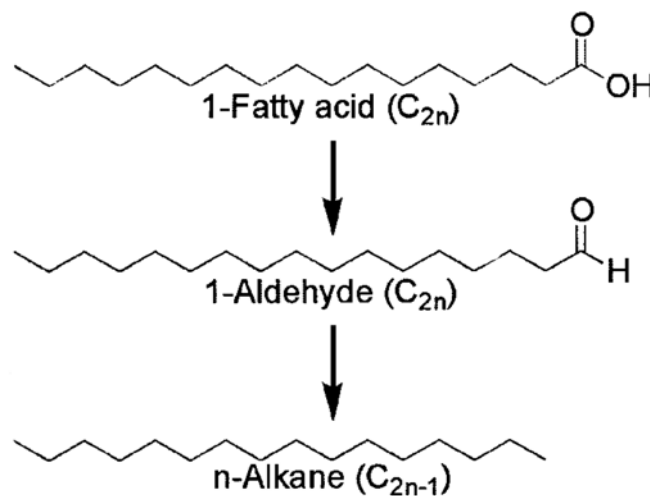
Steps in cellulosic ethanol production



From: Breaking the Biological Barriers to Cellulosic Ethanol

Nature offers many alternatives to ethanol

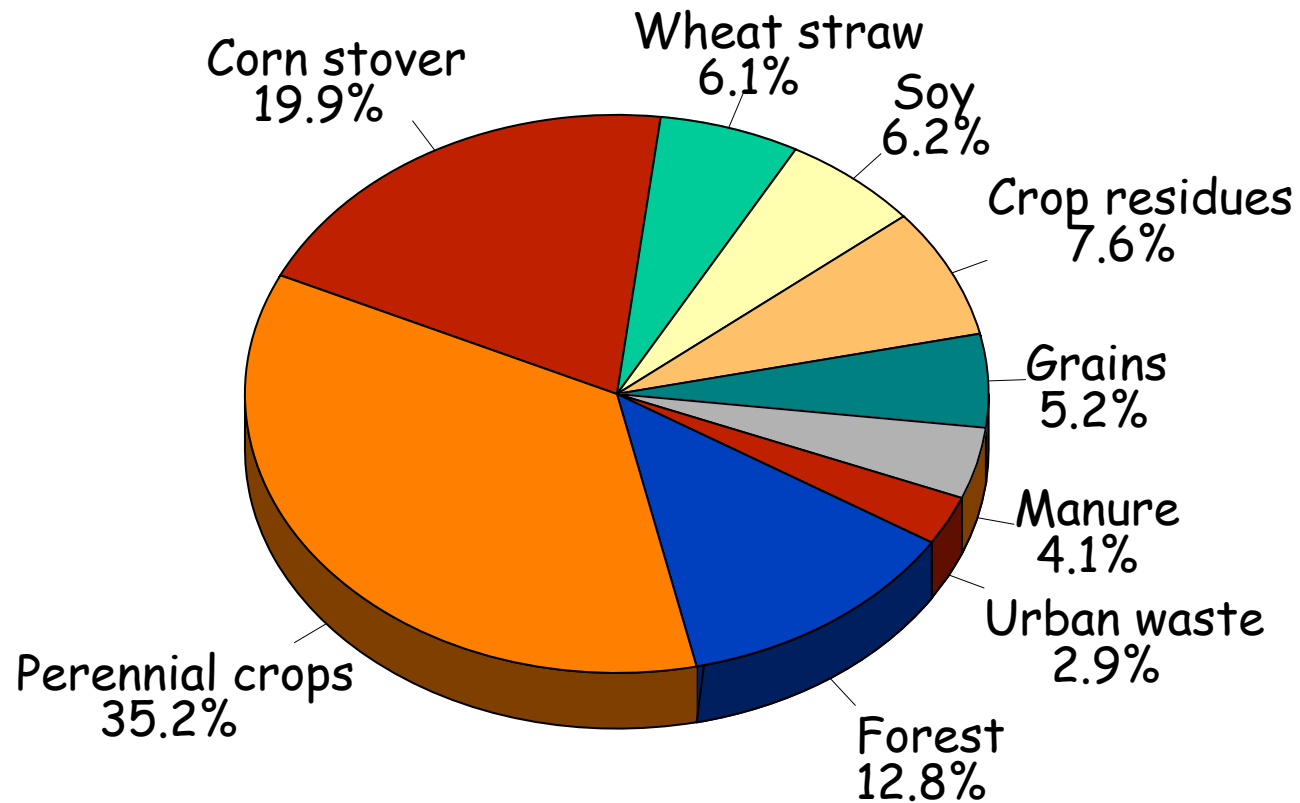
- Plants, algae, and bacteria synthesize alkanes, alcohols, waxes
- Production of hydrophobic compounds would reduce toxicity and decrease the energy required for dehydration



Summary of priorities

- Modify plant composition to minimize energy required for depolymerization
- Identify or create more active catalysts for conversion of biomass to sugars
- Develop industrial microorganisms that ferment all sugars
- Develop new types of microorganisms that produce and secrete hydrophobic compounds

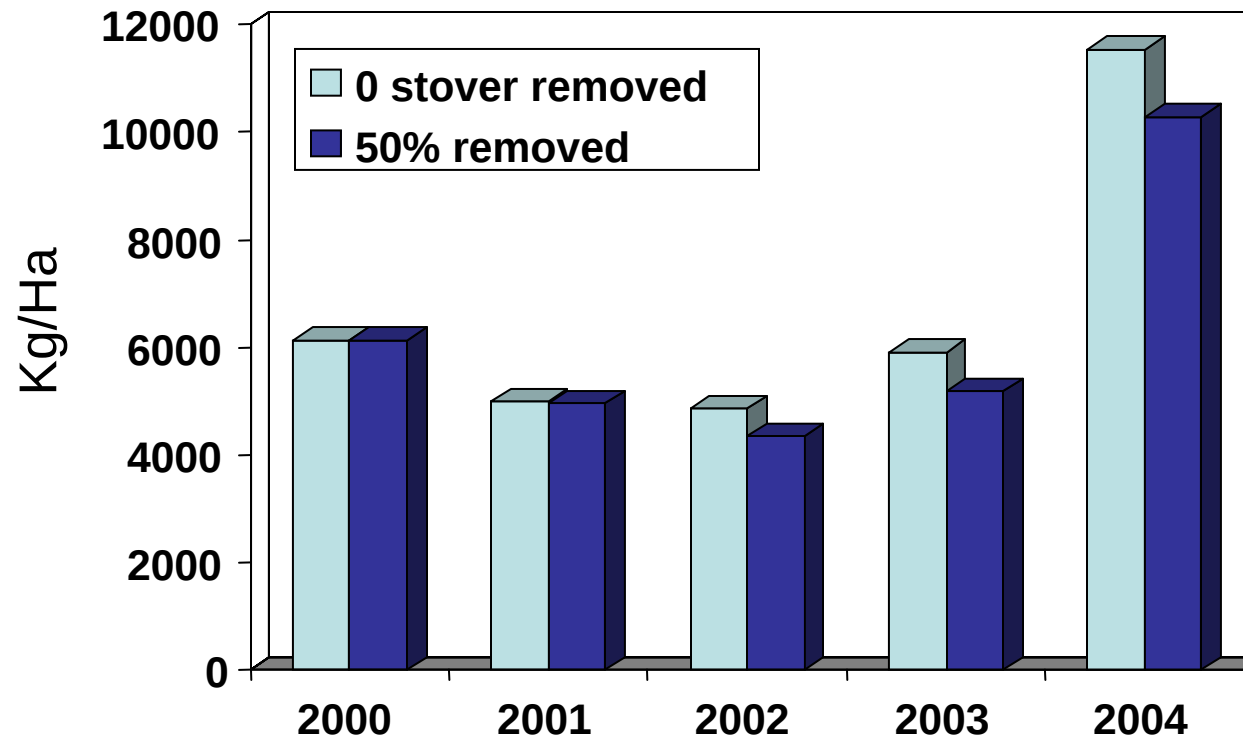
US Biomass inventory = 1.3 billion tons



From: Billion ton Vision, DOE & USDA 2005

Effect of 50% stover removal on corn grain yields in eastern NE.

(120kg N/ha)



K. Vogel et al., unpublished

Prospective energy crops have not been subject to intensive breeding



Miscanthus sp.



Switchgrass (*Panicum virgatum*)

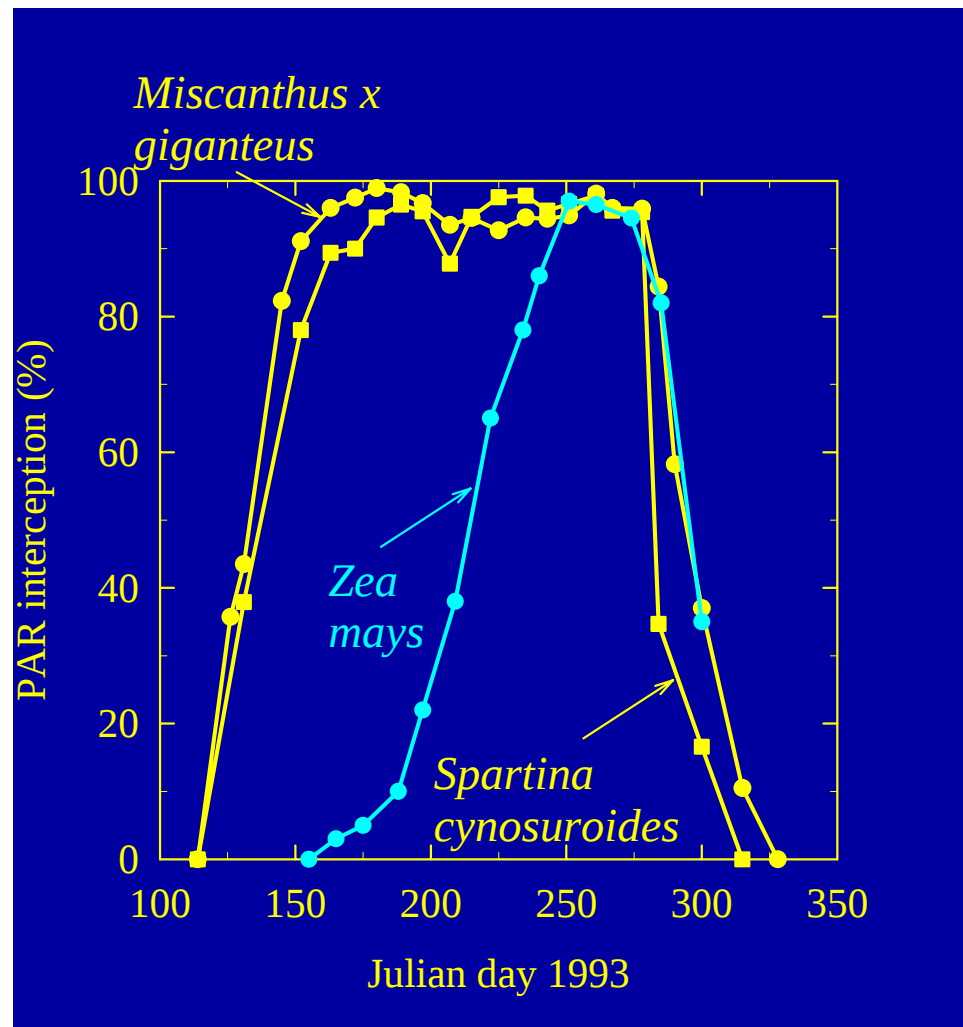
Courtesy of Steve Long & Emily Heaton. USDA-NRCS PLANTS Database / Hitchcock, A.S. (rev. A. Chase). 1950. *Manual of the grasses of the United States*. USDA Misc. Publ. No. 200. Washington, DC.

Harvesting Miscanthus



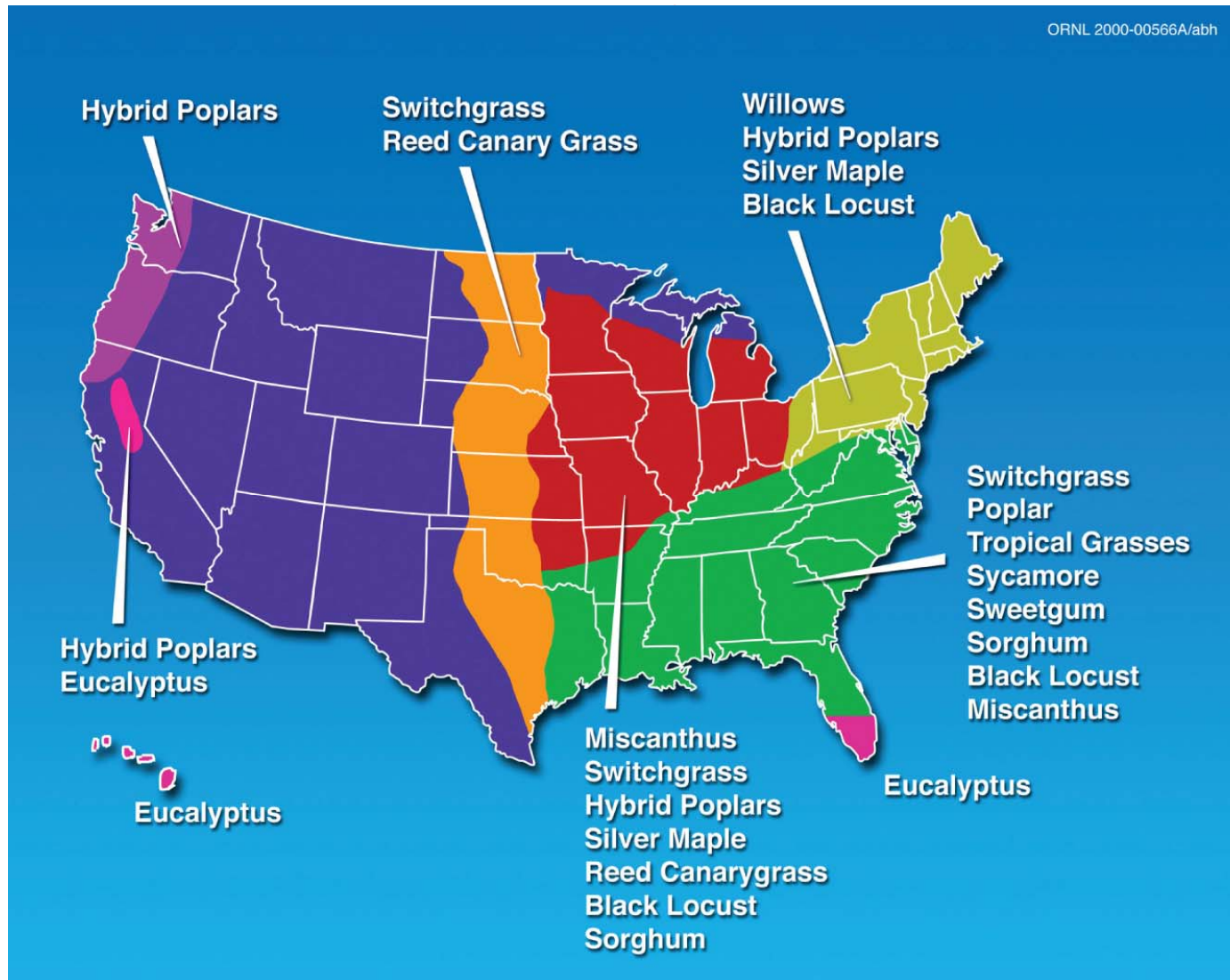
<http://bioenergy.ornl.gov/gallery/index.html>

Perennials have more photosynthesis



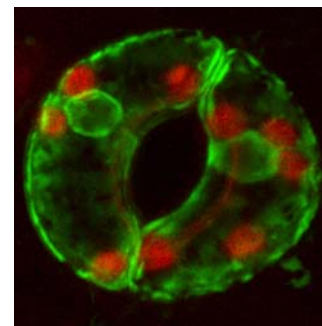
Courtesy of Steve Long, University of Illinois

Geographic distribution of biomass



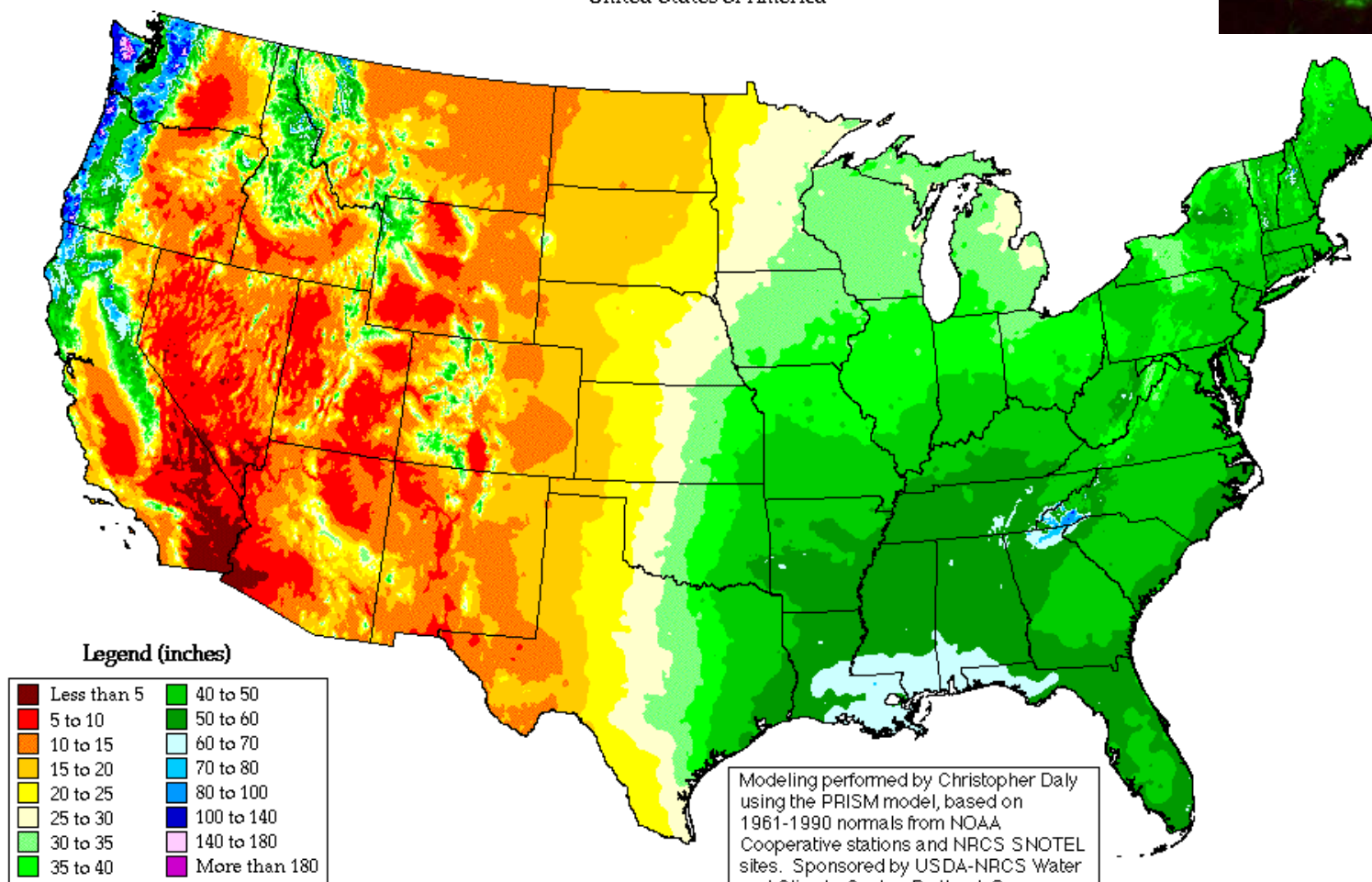
Wright et al DOE-ORNL-EERE

Annual precipitation



Annual Average Precipitation

United States of America



Period: 1961-1990

Modeling performed by Christopher Daly using the PRISM model, based on 1961-1990 normals from NOAA Cooperative stations and NRCS SNOTEL sites. Sponsored by USDA-NRCS Water and Climate Center, Portland, Oregon.

Oregon Climate Service
George Taylor, State Climatologist
(541) 737-5705

Comments

- Energy crops are expected to be more environmentally benign than production agriculture
 - Low fertilizer and chemical inputs
 - Late-harvest supports biodiversity
 - Mixed cultures possible
 - Many species can be used

Research goals for feedstock improvement

- Minimize inputs
 - Perennial energy crops
 - Biotic and abiotic stress tolerance
- Improve propagation
- Maximize biomass yield
 - Establish breeding tools
 - Develop genetic maps
 - Survey genetic diversity
 - Establish orthology to models
- Optimize composition
 - Facile deconstruction
 - Minimal inhibitor production
 - Maximal productivity



Asian soy rust

Economics of Perennials are Favorable

CROP	Yield per Acre	Value \$	Cost \$	Profit \$
Corn (\$4.2/bu) (\$150/t)	160 bu	672	193*	479
Switchgrass (\$50/t)	10 tons	500	138**	362
Miscanthus (\$50/t)	15 tons	750	138**	612

*USDA economic research service 2004

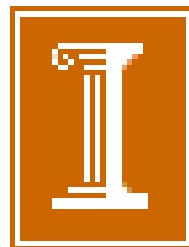
**50% as much fertilizer, no chemicals

Conclusions

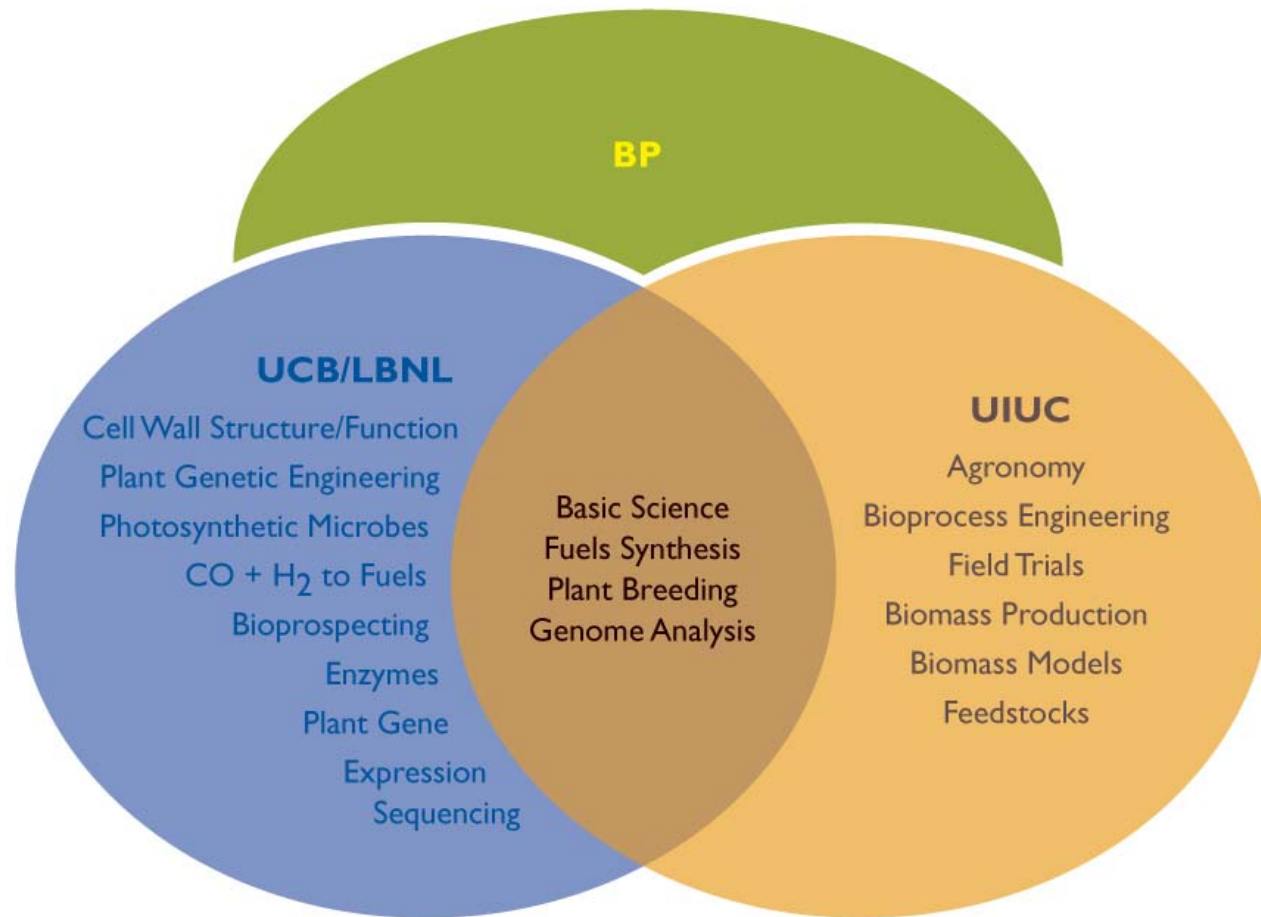
- Biofuels are expected to be an important part of a carbon neutral energy economy
- There are no insurmountable problems
- Many improvements are possible
- The revolution in mechanistic biology offers enormous untapped potential to make fundamental changes in solar harvesting with plants

The Energy Bioscience Institute

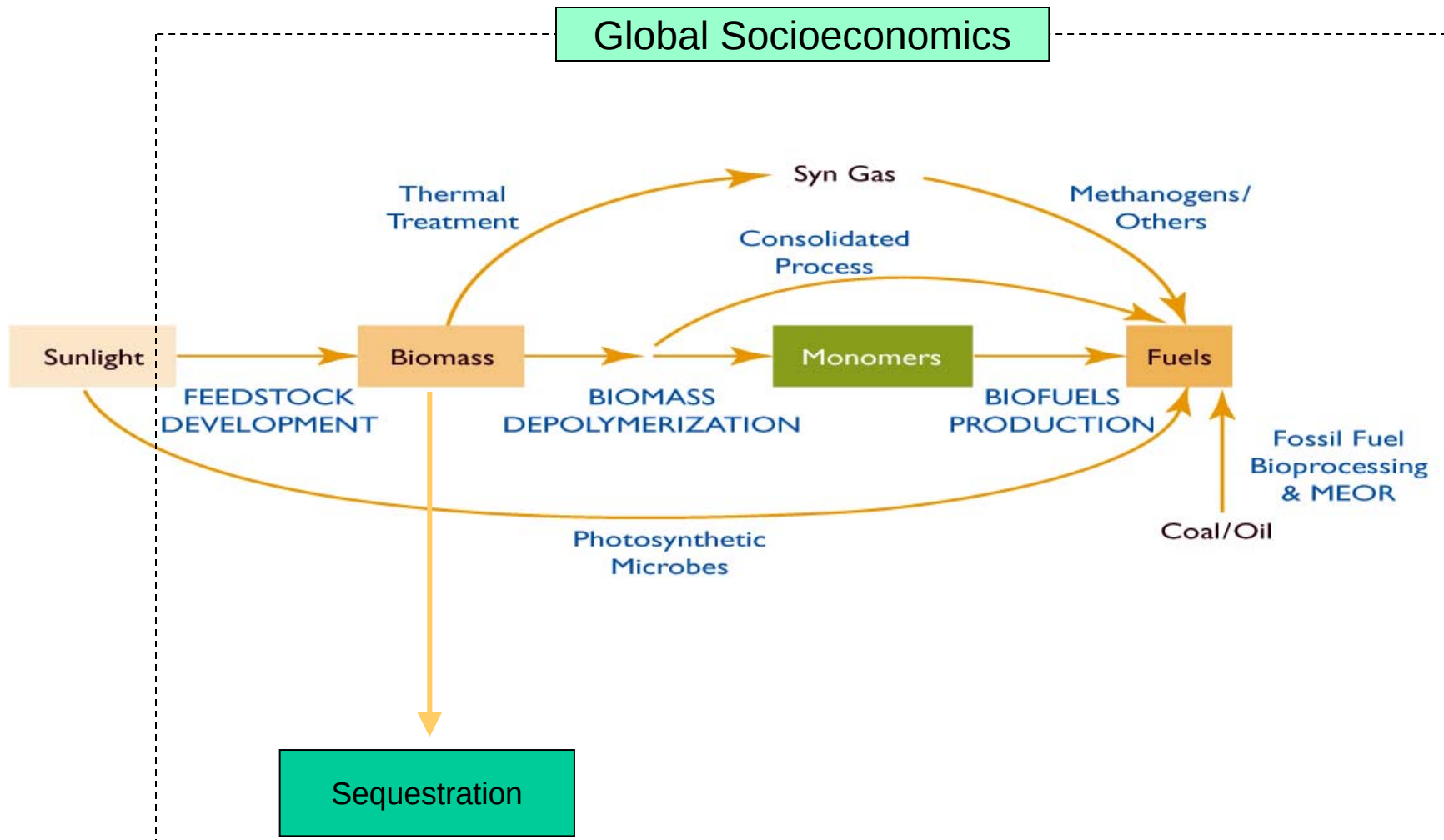
- Partnership between UCB, UI, LBL
- BP has committed \$500M over 10 years
- Goals include elimination of bottlenecks to biofuels, development of improved biotechnologies for fuel production, and education of scientists and engineers across the relevant disciplines



Research Complementarity with UIUC



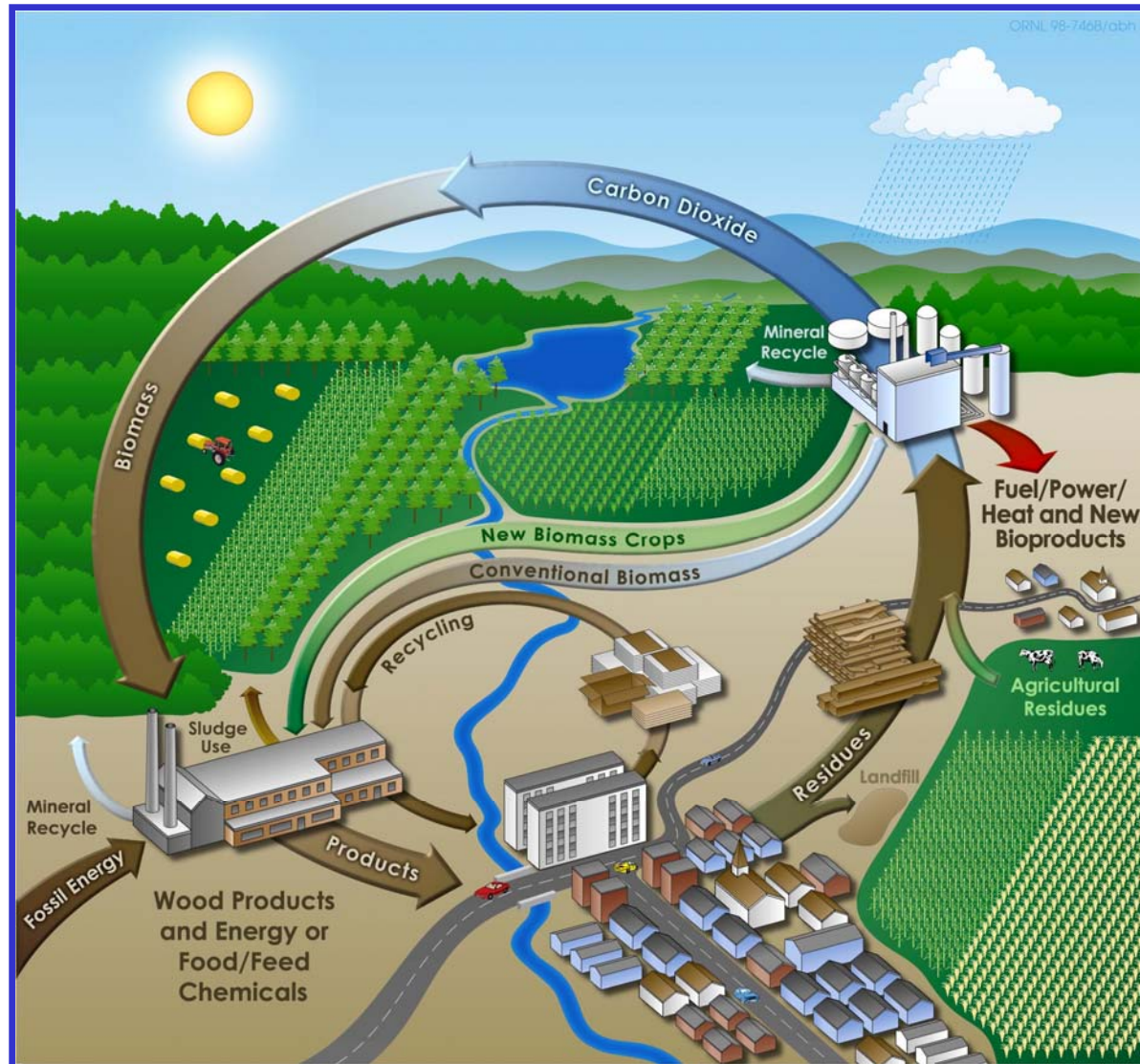
The EBI has Goals Beyond Biofuels



Implementing the program

- Open call for preproposals that address broad goals
- Based on preproposals, PIs will be invited to submit either a project or program proposal
 - Suggestions from executive committee may be attached.
 - Projects will be defined term (EBI associates)
 - Programs will be rolling 3 years with annual reviews (EBI investigators)
- All proposals will be peer reviewed
- EBI investigators will co-locate in EBI space
- EBI associates will have participation obligations

A vision of the Future



<http://genomicsgtl.energy.gov/biofuels/index.shtml>